MINISTRY OF MUNITIONS

AND

'DEPARTMENT OF SCIENTIFIC AND
INDUSTRIAL RESEARCH

Technical Records of

Explosives Supply

1915-1918

No. 3

SULPHURIC ACID CONCENTRATION

The following reports dealing with other aspects of the work of the Department of Explosives Supply have already been published by His Majesty's Stationery Office :—

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PREFATORY NOTE

This is the third of a special series of reports which are being published in order to make available, for the benefit of the industries concerned, results of scientific and industrial value contained in the technical records of the Department of Explosives Supply of the Ministry of Munitions. The work recorded in these Reports was done at, or in connexion with, some of the National Factories during the war. The preparation of the necessary abstracts of information was begun by the Ministry of Munitions at the close of the war, and arrangements were afterwards made by the Department of Scientific and Industrial Research to complete them. The Department wish it to be clearly understood that the interesting information contained in this series of reports is the result of the labours of the Ministry of Munitions, and is being compiled by Mr. W. Macnab, C.B.E., F.I.C., an officer of that Ministry now attached to the Department. The first two reports in the series, "Recovery of Sulphuric and Nitric Acids from Acids used in the Manufacture of Explosives : Denitration and Absorption" and " Manufacture of Trinitrotoluene (TNT)," have already been published for the Department by His Majesty's Stationery Office.

Department of Scientific and Industrial Research,
16 and 18 Old Queen Street,
London, S.W. 1.

June 1921

SECTION II.

GILCHRIST CONCENTRATION PLANT.

SECTION III.

COTTRELL PRECIPITATION PLANT.

APPENDIX.

SECTION II.

GILCHRIST CONCENTRATION PLANT.

SECTION III.

COTTRELL PRECIPITATION PLANT.

In the Kessler system, the hot gases are first passed over the surface of a shallow layer of acid contained in a pan called the saturex, constructed of volvic stone. Over this pan a short 4-plate tower stands, connected by a wide pipe to a scrubber. The weak acid is fed continuously on to the top plate and flows from plate to plate, meeting the hot gases, which are caused to bubble through the layer of acid on each plate by gallots, and so into the "saturex," and thence, in concentrated form, to the cooler.

The Gaillard plant consists essentially of a large hollow tower built of volvic stone or acid-resisting tiles. Dilute acid is sprayed in at the top and meets hot gases from a furnace, which enter at the bottom and pass away at the top, carrying most of the water contained in the acid as well as some of the acid in the form of mist, which is caught in the coke scrubber.

The Gilchrist plant is a combination of a shallow covered-in pan connected with a high tower packed with broken quartz and pottery rings. The dilute acid is fed in at the top of the tower and percolates through the packing, meeting the hot gases which enter the far end of the shallow pan, and which pass over the surface of the acid, and then up the tower and ultimately to the scrubber filled with quartz. The concentrated acid flows out from the end of the pan at which the furnace gases enter.

Spent sulphuric acid contains considerable quantities of sulphates of iron and lead in solution and suspension, resulting from contact with the plant in which it has been used, and these sulphates are deposited as the acid is heated and concentrated, and form a sludge, which has to be removed periodically from the concentration plant. The ease and rapidity with which the sludge can be removed is of importance in considering the design of the various concentration plants.

An account is given of the construction and operation of the Gaillard towers, together with a heat balance for this plant and the gas producers used in connection with it. The working out of such a heat balance necessitates a close study of the mechanism of sulphuric acid concentration, and affords an excellent example of physico-chemical knowledge as applied to plant operations. The Gilchrist plant is treated somewhat in the same manner, though not so fully, as the experience gained with this type of concentration unit is of a far more limited nature.

The electrostatic treatment of sulphuric acid mist by the Cottrell precipitation plant is dealt with at some length in the concluding section, and is followed in the appendix by a short treatment of the subject of free cross-section through coke filters.

H.M. FACTORY QUEEN'S FERRY.

GENERAL ARRANGEMENT OF GAILLARD CONCENTRATION PLANT.

FIG. I.

ELEVATION

PLAN

Gas Flues

Recuperator

Main Tower

Furnace

Scrubbers

Scrubbers

Pumps to Main Storage

Concentrate/Acid Storage

Blow Casks

HOUSE B.

Recuperator Acid Tanks

Scrubber Acid Tanks

Lead Duct for Gases

Cottrell Drip Acids

HOUSE A

Cottrell Precipitator

Transformer House

Fan House

Stack

Spent Acid Tanks

D.M.A. Tanks

2240
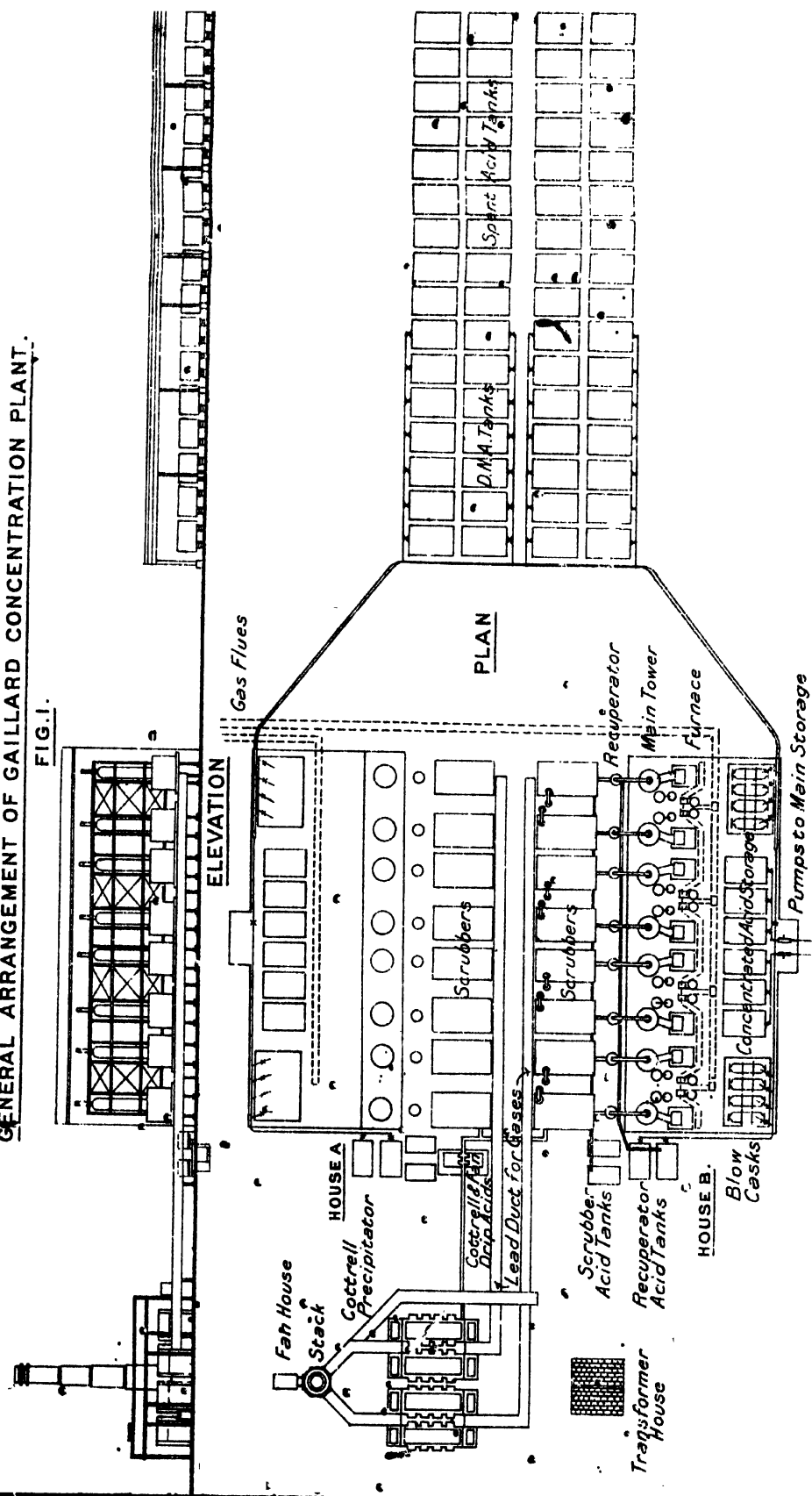
and is elevated to the recuperator acid tanks and again passed through the system. The mist precipitated electrically in the Cottrell precipitator is also elevated and reintroduced into the Gaillard feed system.

Gas Circulation.—Producer gas of moderately low calorific value is supplied from the gas producing plant and burnt with excess of air in the combustion chamber immediately in front of each tower. It is supplied to the furnace through two or three, 8-inch diameter gas valves.

The resulting high temperature burnt gas is drawn by a high pressure Kestner fan through the main tower, meets the descending spray of weak acid and carries away with it the steam evaporated from the minute droplets and also a small amount of sulphuric acid.

The gas leaves the top of the main tower at a temperature near 200° C. through a 24-inch earthenware or silicon-iron pipe to the base or the top of the recuperator, according to the unit design. Here it meets a further spray of acid and a heat exchange takes place. The gas, cooled to a temperature of 140° C. approximately, then passes to the base of a large coke scrubber, ascends through this, being in part deprived of its mist, and passes out of the top of the scrubber to a high pressure Kestner fan, which forces the gas through a lead conduit to the Cottrell precipitator, where it is deprived practically of all its acid, and then through the precipitator stack to atmosphere—the gas after leaving the fan being in addition drawn to the precipitating plant by the suction resulting from an ejector fan at the base of the Cottrell stack.

DESCRIPTION OF THE PLANT.

Furnace and Combustion Chamber.—Fig. 3 shows the general arrangement. The producer gas is transmitted from the gas producing plant through a brick-lined culvert (3 feet wide by 4 feet high) and supplied to each combustion chamber through 8-inch mushroom valves. The combustion chamber is 5 feet 6 inches by 6 feet by 4 feet, and the whole is completely encased in steel which is covered with a thick asbestos lagging to reduce radiation losses to a minimum.

The two outer gas valves supply gas to the rear of the furnace at the base of the combustion chamber and to the centre. The third central valve delivers to the front in the centre of the front section of the furnace immediately at the base of the bridge wall.

The primary air is deflected and delivered through a brick chequer into the front of the furnace. In some cases a portion is deflected to the rear of the furnace. In all cases gas and air channels are distinct, no mixing of gas and air takes place in these channels. The secondary air is delivered through an additional port on either side to the top of the furnace.

Combustion of the gas takes place in the furnace and vertical combustion chamber, and the gases are led to the base of the main tower through a circular brick flue of 9-inch walls and of 27 inches internal diameter.

FIG. 2.

H. M. FACTORY QUEEN'S FERRY

GAILLARD CONCENTRATORS

DIAGRAM SHEWING PATH OF GASES FROM COMBUSTION CHAMBER TO STACK.

Tower

Gas B.T.U. 128·5
CO₂ 5·4
CO 22·2
CH₄ 1·8
H₂ 12·4

Combustion Chamber

Gas Flues

Mud Box Cooler

Feed 69·3%

Recuperator

Scrubber

Fan
16 in. 1260 R.P.M.

Precipitator

Stack

Fan

H. & G. GRAHAM LTD LITHO LONDON, S.E.
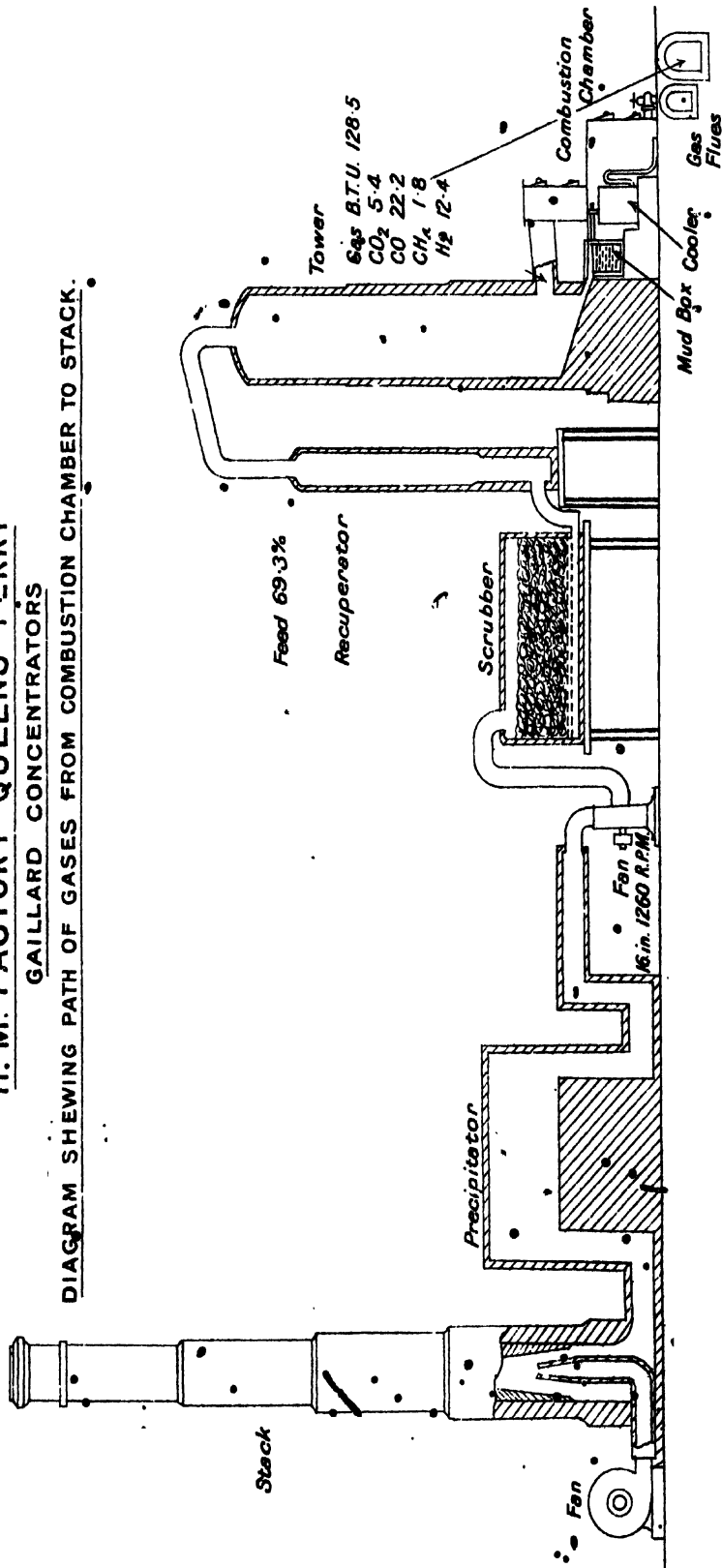
H. M. FACTORY QUEEN'S FERRY.
DETAILS OF MODIFIED GAILLARD FURNACE.

SECTION C.C.

SECTION D.D.

SECTION E.E.

SECTION A.A.

SECTION B.B.

FRONT ELEVATION

FIG. 3.

Air Ports

Gas Valves

Air
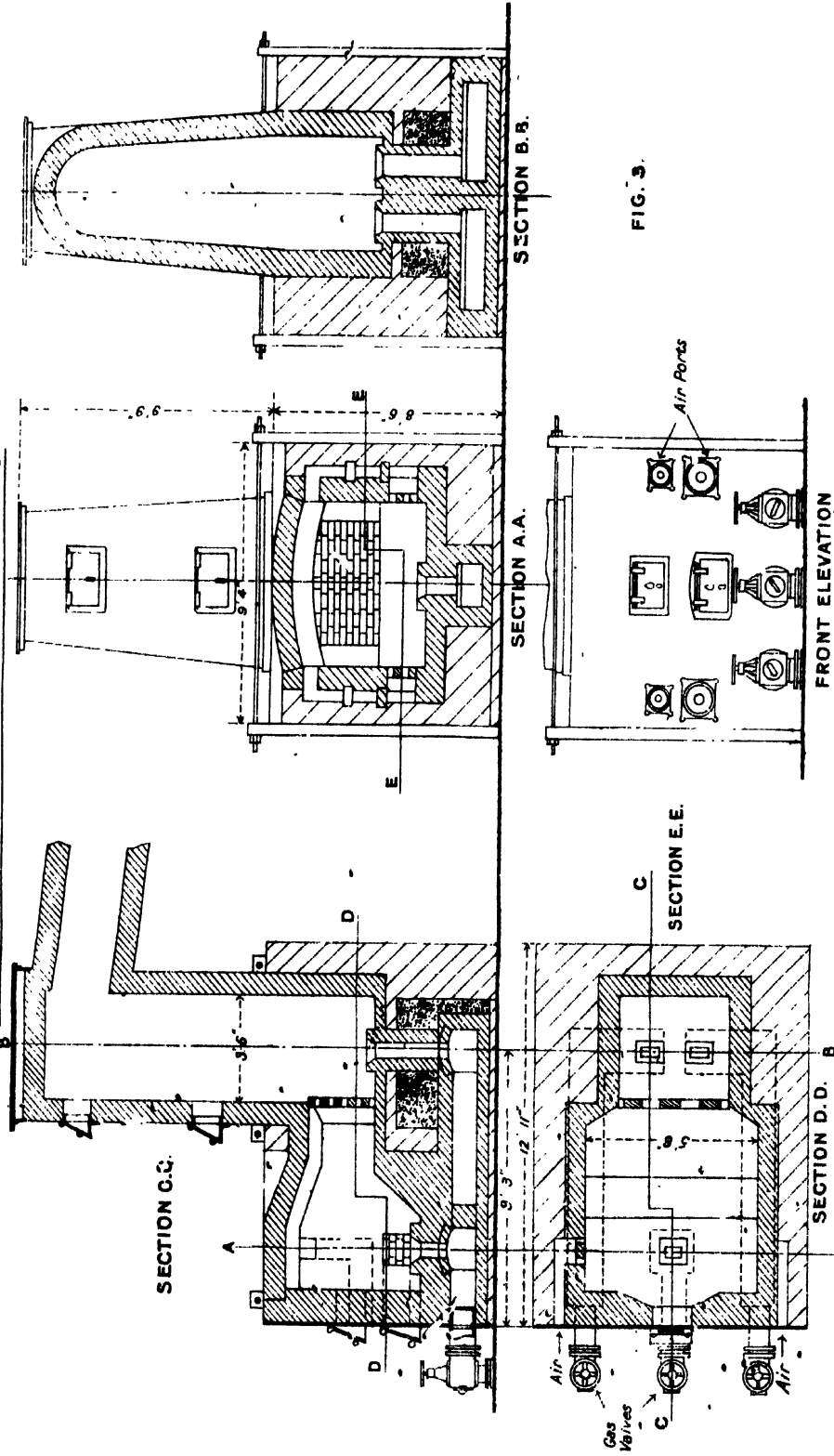
In this type of furnace, with a gas pressure of $\frac{1}{2}$ to 1 inch water gauge, and using the three valves :—

(a) a temperature of 1,000°—1,100° C. is easily maintained.

(b) excessive heating of the frontal arch is avoided.

(c) by separating the gas and the air channels all local heating at the *point of mixture in the channel* is avoided and consequently no melting of the brickwork can occur.

Careful analysis of the burnt gases shows no unburnt CO entering the main tower.

Main Tower.—This consists of a hollow shaft. At Gretna the towers are built of volvic stone, but at Queen's Ferry of acid-proof bricks with joggle joints, in rings each 3 inches thick, with special bonder courses inserted where the number of rings is reduced. The total height of the tower from the base to the springing of the dome top is 47 feet 6 inches, and the internal diameter of the lower 13 feet 6 inches is 8 feet 6 inches, the internal diameter of the remainder being 9 feet.

The lower portion of the tower is built up of six rings of blocks each 3 inches thick. At the height of 13 feet 6 inches the inner course is stopped off and bonded to the adjacent course and the tower is then carried up a further 10 feet in five rings of blocks, each 3 inches thick, the inside diameter being 9 feet. A further 11 feet 8 inches of the tower is built up of four rings each 3 inches thick, the outer course of the section below being stopped and finished off by a bonding course. The remainder of the tower to the springing of the dome is built of three rings, each 3 inches thick.

The top of the tower is a dome struck to a radius of 7 feet 5 inches in its inner surface, and is built up of acid-proof blocks springing from a springing course bound together by a 6 inch × $\frac{1}{2}$ inch mild steel strap.

The blocks of the tower are bound together by circumferential hoops of mild steel spaced about 20 inches apart. These hoops are each in three sections and are covered with lead to resist corrosion.

Generally it is found advantageous to cover the towers completely with sheet lead.

The tower is formed with a sloping floor, the slope being 4 feet, this floor discharging the acid into the mud box. An opening in the wall of the tower, just above the top of the mud box, 15 inches by 2 feet 2 inches wide, is left so that the sludge collecting on the sloping floor may be raked into the box when necessary. The tower and mud box stand in a dish of 30 lb. lead on a heavy concrete foundation.

The tower dome is provided centrally, and, in some cases, peripherally with a 24-inch diameter gas outlet and 5-9 spray blocks for the reception of the atomisers which feed into the main tower. (Fig. 4.)

The atomisers or spray plugs are classified according to the diameter of the orifice in tenths of millimeters. The most common sizes are " 50's " and " 60's," corresponding to orifices of 5 millimeters

and 6 millimeters respectively. The feed capacity of a " 60 " spray at a spraying pressure of 40 lb. is 1 ton of acid per hour.

Tower Offtake.

The tower offtake is formed of silicon-iron pipes 24 inches in diameter, and connects the top of the main tower with the top of the recuperator tower or recuperator box. It is advisable that the offtake should always have a slope so that the acid which condenses in it may gravitate to the vertical section and not linger in the joints.

Recuperator Tower. The recuperator consists of a column 30 feet 8 inches high and of 5 feet external diameter, built up of acid-proof blocks, the lower 14 feet 4 inches consisting of two rings and the remainder of one ring, the lower part having an internal diameter of 4 feet and the upper part of 4 feet $5\frac{1}{2}$ inches.

These rings are built up on a base plate of acid-proof blocks standing in a leaden dish. The bottom course of the rings is formed with outlets for the passage of acid, the overflow level being $2\frac{1}{2}$ inches above the inside of the bottom of the tower. The whole recuperator is covered externally with 9-lb. sheet lead held on by mild steel straps.

In the later concurrent recuperators the top is domed with special acid-proof bricks with a central opening 24 inches in diameter, formed of ring bricks. Six spray blocks are symmetrically arranged for the insertion of six atomisers. (Fig. 4.)

Recuperator Connections.

A 24-inch diameter opening is constructed from the base of the recuperator on the scrubber side, the strength of the structure being insured by the installation of special ring blocks in the wall of the recuperator. From this delivers a 24-inch lead-covered pottery pipe and right-angled bend fitting into the fan-tail to the scrubber.

The base of the fan-tail inlet is covered with $\frac{1}{2}$-inch acid-proof tiles to prevent corrosion of the lead by hot acid.

Scrubber. — The scrubber (Fig. 5) consists of a lead-lined chamber, 30 feet by 16 feet by 11 feet deep, packed with coke of varying size; the gas entering at one end of the bottom and leaving at the top.

The bottom of the scrubber is covered with acid-proof brick laid dry or in silicate of soda, and on this is laid the brick chequer work forming ducts through which the gas is distributed up through the coke.

As the coke is filled in the sides of the scrubber are lined with acid-proof tiles $1\frac{1}{2}$ inches thick, this lining being also laid dry and carried to a height of 6 feet. Spaces at the bottom 2 feet 5 inches wide in the chequer are filled up with large pieces of coke carefully laid so as not to disturb the arrangement of the brickwork, and on this is then laid over the whole of the brickwork a layer of 4-inch coke about 8 inches thick, and above this a layer of coke about 4 inches thick,

Tower

Silican-Iron
Off-take

Regulus Sprays
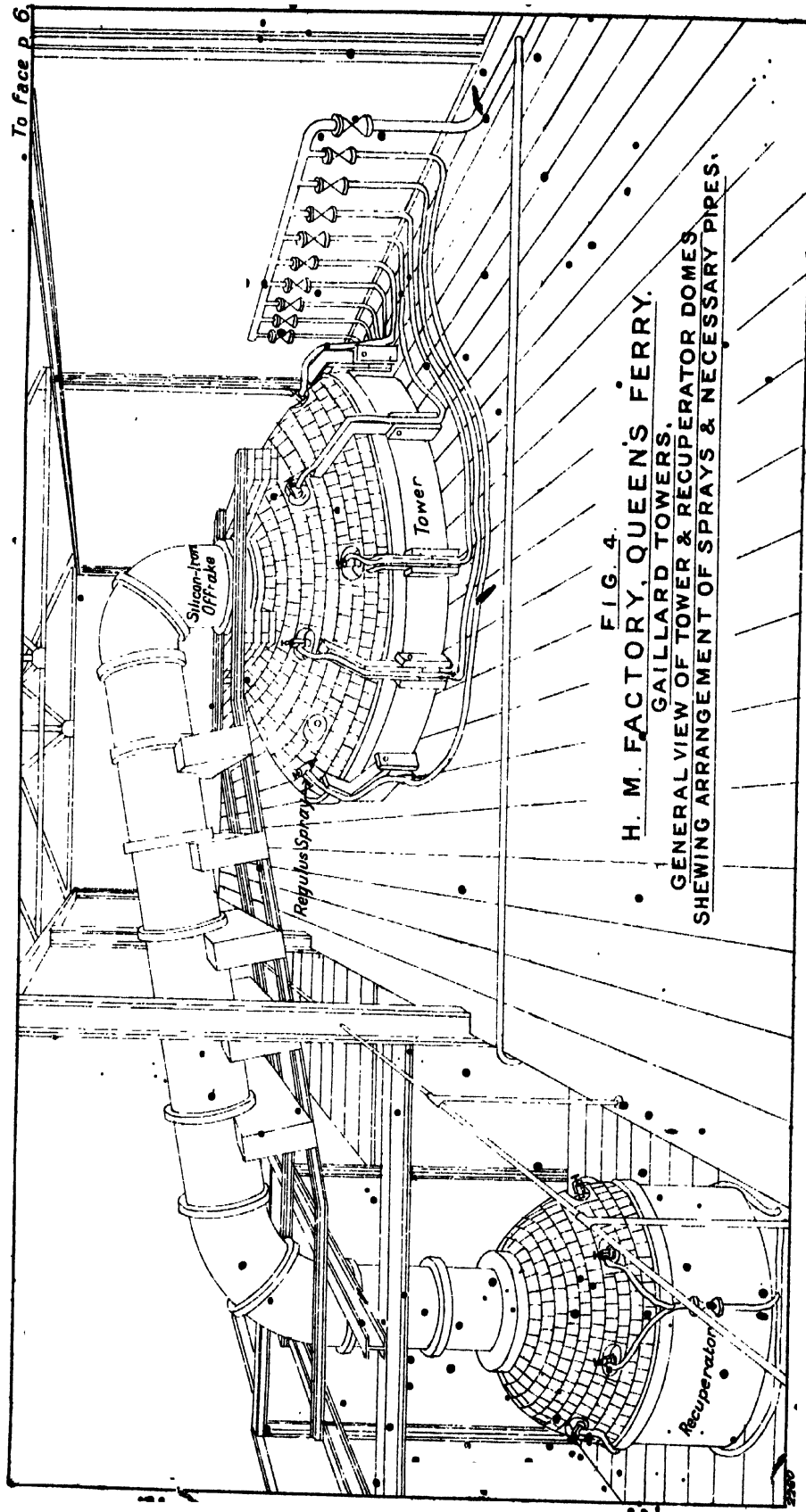
Recuperator

FIG. 4.

H. M. FACTORY, QUEENS FERRY.

GAILLARD TOWERS.

GENERAL VIEW OF TOWER & RECUPERATOR DOMES
SHEWING ARRANGEMENT OF SPRAYS & NECESSARY PIPES.

H.M. FACTORY QUEENS FERRY.

SECTION THROUGH COKE SCRUBBER AT GAILLARD TOWERS.

SCALE ¼ IN—1 FT.

FIG 5.

1½" to ⅜" Coke

2" Coke

4" Coke

30'

Outlet

Inlet

2260
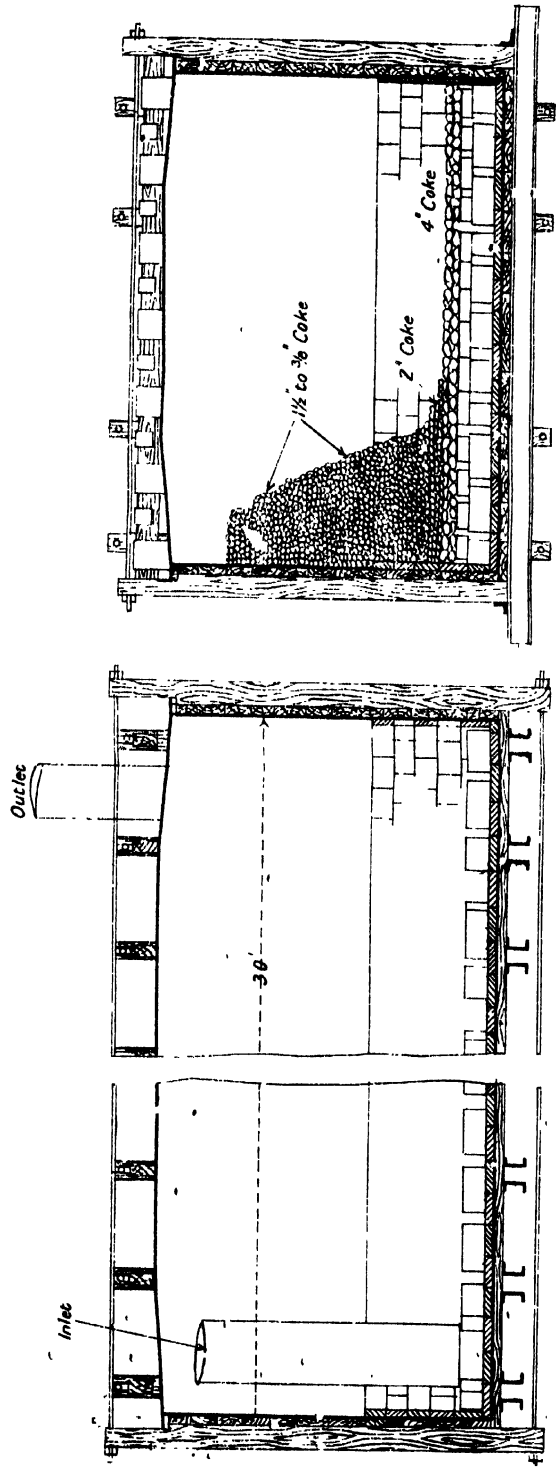
varying from 2 to 1¾ inch in size. The remainder of the scrubber is filled to within 15 inches of the top with screened coke, varying uniformly from 1½ inch at the bottom to ⅜ inch at the top.

The outlet from the scrubber is at the end remote from the recuperator and consists of an 18-inch lead pipe (12-lb.) descending in two bends to the Kestner fan immediately below the scrubber.

Fan.—The fan is a high-pressure Kestner fan supplied by Messrs. Kestner of London. Two sizes are installed—(a) 16-inch; (b) 21-inch (two designs). The fan is constructed of lead and regulus metal studded to a metal framework centrally pierced to accommodate a regulus steel or phosphor-bronze bladed impeller. In the 16-inch fan the shaft runs in bronze bearings oil lubricated. In the original design of the 21-inch fan, the bearings are supplied water-jacketed for cooling, whilst in the latter type of 21-inch fan the oil bath is cooled by water circulating through a copper coil immersed in it.

The exhaust from the fan delivers through an 18-inch circular pipe to one of the two rectangular ducts leading to the Cottrell precipitator.

All fans are belt driven, the motors being of Westinghouse design, and totally enclosed.

The speeds of the impellers are adjusted by alterations of the size of the driving pulley on the motor.

Mud Box.—The mud box consists of a cylindrical box 4 feet 6 inches by 4 feet 6 inches deep, into which the acid from the Gaillard tower runs. It is built up of acid-proof bricks enclosed within a leaden box of 30-lb. sheet lead. Acid is drawn off through a 2½-inch diameter outlet situated about 3 feet above the bottom of the box, and sludge is drawn off through a 4-inch connection at the bottom controlled by a regulus plug and blank flange.

Acid delivers from the mud box through a special sleeve section to which is attached a 2½-inch bore silicon-iron pipe which dips below the surface of the acid in the cooler. Designs of both sleeve section and silicon-iron pipe are shown in Fig. 6.

Coolers.—The new cooler is 3 feet 6 inches internal diameter and 4 feet 8 inches deep, with a steel jacket 4 feet ½ inch in diameter, and 3 feet 6 inches deep, in addition to which three lead cooling coils are provided, which are 21 inches, 29 inches, and 30 inches diameter respectively, and of 1-inch lead piping.

At the top of the cooler an additional 2-inch aperture is arranged with a lead pipe delivering to the funnel pipe leading to the storage tanks. In the case of the bottom outlet becoming blocked, this allows the acid to overflow direct to storage, thus avoiding overflow into the water jacket with risk of damage to the steel annulus.

The total cooling surface exposed to the water is:—

(a) Coils - - - - - - 168 square feet.
(b) Water jacket - - - - - 38 „ „

The amount of water delivered by each cooler (coils and jacket) under the present arrangement is approximately 7 tons per hour.

Storage Tanks for Concentrated Acid.—The acid from the coolers discharges into a lead launder supported on the storage tanks. The latter consist of lead-lined vats, 20 feet by 12 feet by 3 feet, supplied with 2-inch outlet pipes connected by gland cocks with a 3-inch mild steel main leading to two 10-inch Rees Roturbo pumps in each house which deliver along 3-inch mains to the storage tank.

Supply Tanks, Pipe-Lines, Eggs, &c.—The feed acid storage at the denitration plant comprises a battery of 28 tanks, each measuring 20 feet by 12 feet by 7 feet 6 inches, and lined with 12-lb. lead. The weak acid gravitates to the horizontal eggs first through a 6-inch lead main to the two houses, this line dividing into two 4-inch mains at either end of the denitrated acid storage house. These mains deliver in both houses to a set of eight horizontal blow-casks by 3-inch branch lines.

Horizontal Acid-Eggs.

These eggs are built in three sections, the two end sections being identically alike, each being spherically ended with a 14-inch diameter manhole closed by a cast-iron cover. The egg is 4 feet 2 inches diameter inside, and 18 feet 6 inches long, the middle section being 5 feet long and the thickness of the metal in the body 2¼ inches. The whole is lead-lined inside and all joints are made with lead. Each egg is supplied with a 2-inch Cortin pillar valve at the outlet, and at the discharge with a 2-inch Cortin horizontal straight through valve.

The rising mains from two eggs branch and join into one 1½-inch main leading to the top of the main tower, a 1-inch branch leading from the spray platform to two recuperators. At the tower top a central 2-inch valve controls the acid supply and from this branch five to nine 1-inch pipes fitted with 1-inch regulus valves for the individual atomisers.

Each house is provided with two lead-lined recuperator tanks, 15 feet by 10 feet by 4 feet. These are connected with the horizontal eggs by an extension of the 4-inch main from the denitrated acid storage.

The scrubber launders deliver, in each house, to two lead-lined storage tanks measuring 15 feet by 7 feet by 4 feet, and from these acid is elevated to the recuperator acid storage.

Acid from the Cottrell precipitators is delivered into two lead-lined storage tanks set in a pit. From here the acid is elevated through 2-inch lead mains by a 1½-inch silicon-iron pump to the recuperator acid storage. These tanks also receive the acid which flows from the luted pipes from the base of the Kestner fans.

General Principles and Routine Working of a Gaillard Tower.

The principle of concentration in the Gaillard tower obviously depends on the evaporating power of large quantities of moderately heated gases, whereby the temperature attained by the evaporating liquid is considerably below the boiling point of the sulphuric acid. In this respect it differs fundamentally from the cascade

FIG. 6.

·H.M. FACTORY. QUEEN'S FERRY.

DETAIL OF SILICON IRON RUN OFF FROM MUD BOX TO COOLER

SCALE 1½ IN =1 FT.

30 lb Lead

Solid Regulus

M.S. Bolts in slots

Silicon-iron Metal

Packing Box, Asbestos, Barytes & Silicate.

Tiles

Mud Box
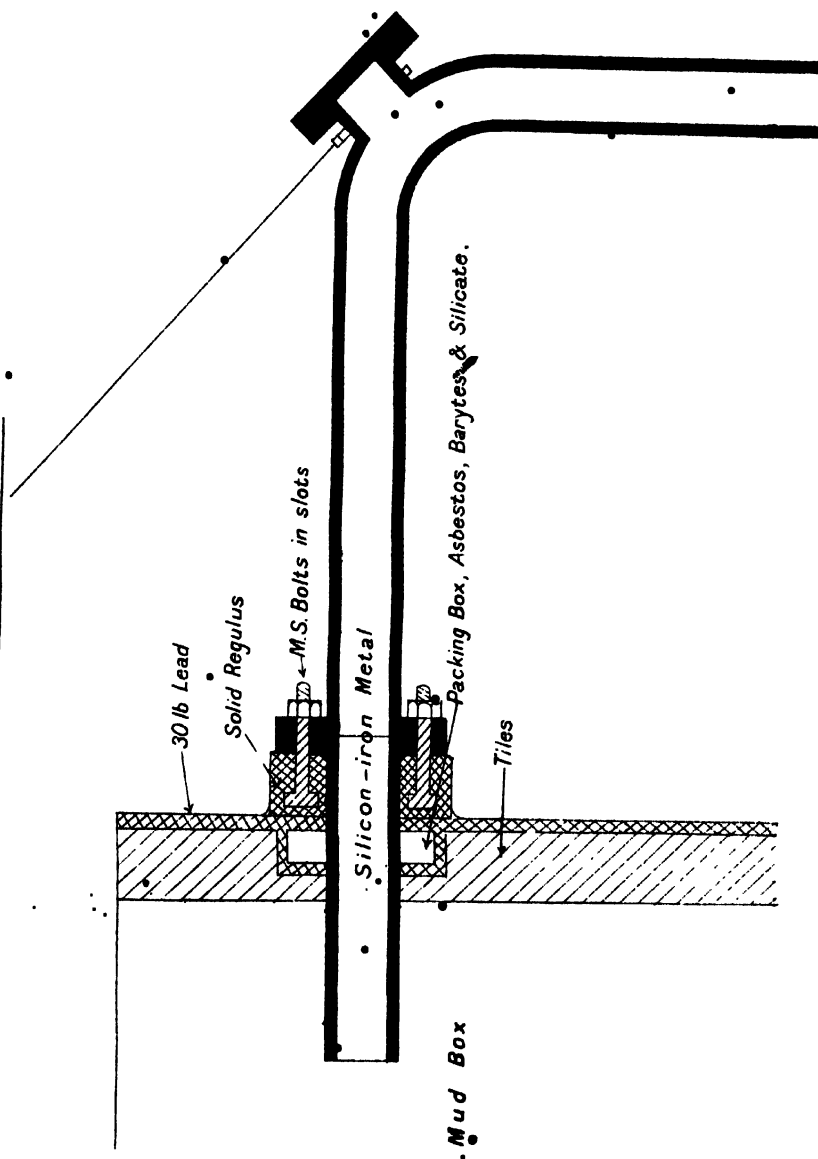
process in which the final evaporation practically occurs at the boiling point of the liquid. The economy in heat requirements is rendered manifest from the fact that in the Gaillard process the hot gases come directly into contact with the evaporating liquid in the form of spray.

A short description of the circulation of acid and gas through the plant has already been given, and an outline will now be given of the normal running conditions and procedure adopted.

Furnace.—The furnace is directly controlled by a chart which gives a continuous record of the furnace temperature at the neck near the tower base. The pyrometers installed are of the Pt/Pt-Rh thermocouple type connected with 24-hour quadruple thread recorders.

Given a constant strength of acid to the main tower, it may be safely said that the main factor in preserving a product of uniform strength from the base of the tower is the control and regulation of the furnace temperature. The most suitable temperature for a good production figure per unit is 1,000° to 1,100° C. at the tower inlet.

Main Tower.—The exact course of events in the main tower is not directly known. Much information of great value would be obtained if a series of both temperature and acid concentration gradients could be taken at various heights in the tower. An analysis of these should show precisely the effective region of concentration and point to the ideal method of running.

In normal working, with a feed acid of 65 to 70 per cent. strength and concentrating to a 92 to 94 per cent. product, the heat exchange is such that the gases leave the main tower at temperatures varying from 200° to 220° C. The exact temperature at which the gases leave the main tower is dependent largely on the efficiency or fineness of the atomisation from the feed atomisers and to a less extent on the concentration range required.

Variation of the Final Concentration.—In any particular unit the concentration is varied by :—

(a) Varying the number of atomisers.

(b) Varying the size of the atomisers.

The furnace temperature is generally kept as constant as possible whatever the concentration required. For instance, if it is desired to increase the concentration, say, from 92 to 94 per cent, this is generally effected by preserving the same number of atomisers, but by decreasing their size. The tower outlet temperature remains practically steady by reason of the finer atomisation, thus yielding an increased surface for a given volume of acid. In some cases it is necessary to decrease the number of atomisers, with a consequent slight rise in the tower outlet temperature.

Recuperator.—The gases from the main tower, including steam and small quantities of sulphuric acid, pass without much loss of heat to the recuperator, entering this tower at a temperature of 200° to 210° C. In the later reconstructed units the flow of acid and gas is concurrent. The gases leave the recuperator at temperatures varying from 135° to 155° C., according to the volume of gas or volume of acid sprayed down

the recuperator. The heat exchange is such that acid is heated from 40° to 50° C. to a temperature of approximately 125° C. There is a slight concentration occurring in the recuperator amounting to $1\frac{1}{2}$ to 2 per cent. By repeated circulation of the same acid within the recuperators, the difference in concentration between this acid and the denitrated acid may amount to 3 or 4 per cent. This concentration is in the main effected by condensation of sulphuric acid leaving the main tower.

The gases leaving the recuperator pass directly to the base of the scrubber and are led through the fine coke packing. Scrubber acid condenses on the pores of the coke and gravitates to the base, running into a launder delivering to the storage tanks. The temperature of the acid varies from 100° to 130° C., and the temperature of the gases leaving the scrubbers from 95° to 110° C. Considerable additional cooling is in some units effected by flooding the scrubber top and allowing the warm water to overflow into the drain. In this way the temperature of the gases entering the fan is reduced.

Fans. — The temperature of the gases entering the fan is practically identical with the scrubber outlet temperature and the strength of the acid condensed by baffling in the fan is a function of the temperature of the gases.

The gases from the fan pass along the Cottrell precipitator conduits and enter the precipitation chambers at a temperature 85° to 90° C., according to the air temperature. The gases leave the chambers at approximately 75° C. The strength of the precipitated acid from the Cottrell precipitator varies from 50 per cent. to 53 per cent. of H_2SO_4.

The dependence of the acidity of precipitated acid upon the temperature, whether precipitated mechanically by baffling or electrically in the Cottrell plant, is shown in the following table :—

Temperature of gases. ° C.	Strength of fan drip acid. Per cent. H_2SO_4.
90	55·0
98	56·9
102	59·0
110	59·6

Acid Circulation.—The various amounts of acid delivered from recuperators and scrubbers per diem are as follows :—

(2) Recuperator acid - - 60 tons per tower per diem.
(3) Scrubber acid - - 3 „ „ „
(4) Cottrell precipitator acid 2 „ „ „

Of the six storage tanks for strong acid, one in each house is set aside for taking weak acid delivered from the towers when these are started up. These two tanks are connected with the feed lines to the horizontal eggs, and the acid can therefore return for further concentration.

Starting up a Unit.—In starting up a unit which has been closed down for a considerable time, normal working is not generally attained until after a period of six to eight hours. Working should be guided entirely by the main tower offtake temperature. The first runnings from the cooler are obviously dependent on the strength of the acid originally present in it and in the sludge box.

During normal running, low concentration and a high tower outlet temperature combined, indicate poor atomisation; low concentration with normal temperatures generally indicate leakage of water from the coils of the cooler. This latter error can be easily proved by testing the acid issuing directly from the tower base at the sludge box cover. The leaking coils themselves can be independently tested by shutting off the water pressure from the defective coil for half minute or so, then opening the water valve, collecting the water from the coil exit, and testing with litmus. This method has always been found reliable even for the smallest pinhole leaks.

Shutting down a Unit.—When it is necessary temporarily to shut down a unit in order to effect minor repairs, all fires are cut off from the furnace and all air ports tightly closed. Sprays are removed from the main tower, and the fan is kept running to maintain a clear atmosphere at the dome. Ideally under this system little or no heat should be transferred from the furnace to the main tower. Experience has shown that this method does no harm to any portion of the plant. No excess temperatures occur through the system, for the major portion of the draught through the unit is the cold air drawn in at the spray holes of the main tower and recuperator. This method has certain distinct advantages over the original method of shutting off the fan. These advantages appear to be :—

(1) Clear atmosphere on the spray platforms.

(2) No positive pressure on the tower dome. The effect of pressure on the tower dome is to lead to sweating of acid through the brickwork and so decreasing its life.

(3) If the impeller of the fan is kept at a more or less uniform temperature there is less likelihood of regulus metal becoming detached from the phosphor-bronze blades, since, when the fan is shut off, its temperature rapidly falls.

Thermal Efficiency of the Gaillard Unit.

Given a constant heat supply per ton of coal from the gas producing plant, then, for any one fixed concentration range, the thermal efficiency of a Gaillard unit will obviously depend primarily upon the useful work performed in the main tower. In working two sources of loss of heat in the main tower may appear, other than radiation losses :—

(1) Loss due to decomposition of H_2SO_4 at high initial gas temperature.

(2) Loss due to removal of burnt gases and steam at 200° to 220° C. from the exit of the main tower.

The functions of the recuperator are primarily (a) the cooling of exit gases and recovery of their sensible heat, and (b) the condensation and recovery of most of the sulphuric acid passing out of the main tower.

In its passage down the recuperator, the weak feed acid is raised to a temperature of 120° to 130° C., and in addition becomes slightly concentrated due to the condensation of sulphuric acid mist from the main tower. The sensible heat of the gases, recovered from the major part as sensible heat in the recuperator acid, is lost again through the recuperator coolers, for, in an ideally run plant, this acid is cooled again to a temperature of 50° C., the temperature of the incoming recuperator feed acid being approximately 20° C. Some H_2SO_4 may be decomposed by the heat, but the larger part of the acid is recovered in the recuperator where it condenses. Some, however, passes on to the scrubber and Cottrell precipitator, where it is recovered as weak sulphuric acid.

It follows then that the thermal efficiency of a Gaillard tower also depends upon the CO_2 content of the burnt gases fed to the main tower.

This can be looked at from two aspects. In normal working the tower outlet temperature remains steady in the neighbourhood of 200° to 220° C. The more air admitted to the main tower in excess of the requirements for the complete combustion of a given weight of producer gas, the more waste heat passes out at the top of the tower.

Theoretically, then, the less air admitted in excess of requirements, the lower the fuel consumption, for it is to be noted that during normal working the outlet temperature of the recuperator is kept constant, and it follows therefore that in working to a high CO_2 content of burnt gases the *weight* of gases leaving the recuperator at $t°$ C. is much less than the weight of gases leaving the recuperator at $t°$ C. when the CO_2 content of the gas is kept very low. On the other hand, with very high temperatures corresponding to high CO_2 content of gases, the useful work performed in the main tower may decrease, due to increased dissociation of the sulphuric acid at the base of the tower. Too high a temperature in the furnace is therefore detrimental to concentration.

Queen's Ferry practice is such that as high a temperature as possible is maintained without unduly increasing the dissociation at the base of the main tower.

For consistent working a temperature of 1,000° C. is satisfactory. It has been the practice to limit the furnace temperature to 1,100° C., and for normal running the limits 1,000° to 1,100° C. give good results. These temperatures correspond to 9 to 11 per cent. of CO_2 in the burnt gases for the composition of the producer gas supplied to the plant. High temperatures and CO_2 percentages can and have been obtained, but working to these is not advised.

The limits 1,000° to 1,100° C. have the following advantages:—

(1) No damage is done to the furnace structure.

(2) Complete combustion of the producer gas can be ensured.

(3) Dissociation of H_2SO_4 into SO_3 and H_2O and further into SO_2 is minimised, for it is greater at higher CO_2 percentages.

(4) Utilising the full capacity of the fan at its constant speed, the capacity of the unit is greater than at lower initial temperatures.

FACTORS ON WHICH THE CAPACITY OF A GAILLARD UNIT DEPENDS.

The factors controlling the concentration capacity of a Gaillard tower yielding a definite constant strength product are:—

(1) The volume of gas passed through the tower.

(2) The initial temperature of these gases.

(3) The concentration of the initial feed acid.

(1) *Volume of Gas passed through the Tower.*—This obviously depends on the capacity of the fan and the resistance within the circuit. With a constant resistance the volume treated by a fan is directly proportional to its speed.

(2) *The Initial Temperature of Gases.*—For economic running a temperature of 1,000° to 1,100° C. is most suitable and the majority of test runs have been made at these temperatures.

(3) *The concentration of the Initial Feed Acid.*—This is a very important factor, and one which is often disregarded when comparisons of output of different Gaillard units are made. It is a factor very obviously affecting the fuel consumption, and this being so, when other variables are fixed, it affects the production capacity of the unit likewise.

THE DRAUGHT THROUGH A GAILLARD UNIT.

When first erected the gases from the main tower were conducted to the bottom of the recuperator tower and passed up against a spray of acid. Under these circumstances the following water-gauge readings of the draught were obtained:—

	Inches.
Furnace	0·2
Tower outlet	0·5
Recuperator inlet	1·2
Recuperator outlet	2·0
Scrubber inlet	2·2
Scrubber outlet	3·2
Entrance to fan	3·7

These are average readings obtained with a 16-inch Kestner fan running at 1,440 r.p.m. Any irregularities in working manifest themselves in

"fuming" at the dome of the tower. With the removal of the tower
and the recuperator downtakes and the installation of the direct dome
to dome connection from tower to recuperator, as shown in Fig. 4, the
resistance through the circuit has been greatly decreased, and excellent
draught can be obtained with a 16-inch fan running at a speed of
1,300 r.p.m.

The first tower reconstructed with a concurrent recuperator gave
the following draught readings when the 16-inch fan was running at
1,260 r.p.m. :—

	Inches.
Furnace - - - - - - - -	0·1
Tower outlet or recuperator inlet - -	⎫
Recuperator outlet - - - - - -	⎬ 0·4
Scrubber inlet - - - - - - -	0·5
Fan - - - - - - - -	1·8

At 1,440 r.p.m. these readings became :—

Furnace - - - - - - - -	0·1
Tower outlet - - - - - -	0·6
Recuperator outlet - - - - -	0·9
Fan - - - - - - - -	2·4

The great difference between those readings and those obtainable
on a counter-current is manifest.

HEAT REQUIREMENTS FOR CONCENTRATION.

The fuel consumption on a Gaillard concentrating plant varies
not only with the method of working but also with the concentration
range. The variation in heat requirements for various concentration
gradients which occur in practice, and also the variations induced
by varied methods of working, will now be reviewed.

**The Influence of the Initial and Final Acid Concentration Strengths on
the Fuel Concentration in a Gaillard Unit.**—The initial and final strengths
of acid which pass through a concentration plant vary according to
the type of process and the method of working of the associated
plant. For most Gaillard plants the following limits will apply:—

(1) Initial feed acid   -   - 65 to 78 per cent. H_2SO_4.
(2) Final concentrated acid - 92 to 96 per cent. H_2SO_4.

The thermal requirements will hereafter be reduced to fuel con-
sumption per ton of product.

Standard Conditions in a Gaillard Unit.—The conditions existing in
the main tower will be standardised throughout as:—

(a) Initial state   -   -   - Feed acid at 15° C.

(b) Final state -   -   -   ⎰ Concentrated acid at 220° C.
                                 ⎱ Steam at 220° C.

The relationship between the heat requirements in the Gaillard
tower and the strength of the initial feed acid will be first discussed

for a constant concentration product of 92 per cent. H_2SO_4. A typical example of Queen's Ferry practice being taken as under :—

(a) Initial feed, 65 per cent. H_2SO_4.
(b) Final product, 92 per cent. H_2SO_4.

In a paper on the "Thermal properties of sulphuric acid and oleum" (Trans. Farad Soc., Vol. XIII., Pt. 3, 1918), A. W. Porter, F.R.S., has drawn up a series of tables and graphs, Fig. 2, from which the heat required for concentrating from any one strength to any other strength can be rapidly determined. In the following work these tables are exclusively used :—

The heat required may be divided into two stages, viz. : —

(1) Heat of total evaporation at constant temperature.
(2) Sensible heat at constant concentration.

The heat of total evaporation at constant temperature consists of :—

(a) Latent heat of evaporation of water.
(b) Differential heat of dilution.*

Then, from Porter's tables, for 1 lb. of SO_3 :—

(1) The sensible heat of acid containing 65 per cent. of H_2SO_4 (i.e., containing 53 per cent. of SO_3) between 15° and 220° C. = 204 C.H.U.
(2) The heat of evaporation for acid concentrated from 65 per cent. to 92 per cent. H_2SO_4 (i.e., 53 per cent. to 75 per cent. SO_3) at 220° C. = 352 C.H.U.

∴ Total heat required = 556 C.H.U.

∴ For 100 lb. of 92 per cent. H_2SO_4 (75 lb. SO_3) = 75 × 556 = 41,700 C.H.U.

or for 1 ton $= \dfrac{41,700 \times 2,240}{100} = 934,100$ C.H.U.

The heat of evaporation 352 C.H.U. may be calculated from the formulæ in Porter's paper as follows :—

The heat of total evaporation is the sum of the latent heat of the water at the temperature and the differential heat of dilution.
Latent heat of water at 220° C. (365° critical point)
$$= 83\cdot 9\,(365 - t°)^{\frac{1}{2}}$$
$$= 83\cdot 9\,(365 - 220)^{\frac{1}{2}}$$
$$= 440\cdot 7 \text{ C.H.U.}$$

Differential heat of solution—

$$(H) = \frac{504\cdot 2\,M}{M \times 0\cdot 2013} + \frac{0\cdot 714\,M\,(t - 15)}{M \times 0\cdot 062}$$ where M = lb. of water per lb. of SO_3.

_____

* This quantity is ascertained from Brönsted and Pfaundler's values.

For a 53 per cent. solution, the amount of water to 1 lb. of SO_3 is 0·887 lb.

$$H = \frac{504·2 \times ·887}{·887 + ·2013} + \frac{·714 \times ·887 \times (220 - 15)}{·887 + ·062} = 547·5 \text{ C.H.U.}$$

Heat of total evaporation for 53 per cent. acid at 220° C. is $(440·7 \times ·887) + 547·5 = 938$ C.H.U.

For a 75 per cent. solution the amount of water to 1 lb. of SO_3 is 0·333 lb.

$$H = \frac{504·2 \times ·333}{·333 + ·2013} + \frac{·714 \times ·333 \times (220 - 15)}{·333 + 0·062} = 437·7 \text{ C.H.U.}$$

Heat of total evaporation for 75 per cent. acid at 220° C. is $(440·7 \times ·333) + 437·7 = 584·4$ C.H.U.

For concentration from 53 per cent. to 75 per cent. SO_3 the heat of total evaporation is $(938·5 - 584·4) = 354$ C.H.U.

It is of interest to note the closeness with which Porter's values agree with the method utilising Thomsen's heat of dilution formula. Taking the same concentration range, 65 per cent. to 92 per cent., as before, then—

(a) Initial state: 141·6 gm. of 65 per cent. H_2SO_4 at 15° C.
(b) Final state: 100 gm. of 92 per cent. acid at 220° C.
           41·6 gm. of steam at 220° C.

The total heat necessary becomes :—

(1) Acid heat: $100 \times 0·35 \times 205 = 7,175$ calories.
(2) Steam heat : $41·6 \times 0·45 \times 120 = 2,246$ calories.
(3) Latent heat of evaporation : $41·6 \times 536 = 22,297$ calories.
(4) Water heat; $41·6 \times 1 \times 85 = 3,536$ calories.
(5) Thomsen's formula for the heat of solution Q of H_2SO_4 in water

is $[H_2SO_4, nH_2O] = \dfrac{n \times 17,860}{n + 1·798}$.

The heat of solution of the initial and final strength of the acid is calculated and the difference is the heat of solution sought.

In the initial acid 49·6 lb. of water are associated with—
           92 lb. of H_2SO_4.

In the final acid 8·0 lb. of water are associated with—
           92 lb. of H_2SO_4.

The equation $Q = \dfrac{n \times 17860}{n + 1·798}$ then becomes as follows :—

$$Q = \frac{92}{98} \left[\left\{ \frac{17,860\left(\frac{49·6 \times 98}{18 \times 92}\right)}{\frac{49·6 \times 98}{18 \times 92} + 1·798} \right\} - \left\{ \frac{17,860\left(\frac{8 \times 98}{18 \times 92}\right)}{\frac{8 \times 98}{18 = 92} + 1·798} \right\} \right] = 6,900 \text{ calories.}$$

The sum of the C.H.U. under these five items is 42,150 C.H.U., and this represents the total heat necessary to concentrate 92 lb. of H_2SO_4 (or 75 lb. of SO_3) from 65 per cent. to 95 per cent. sulphuric acid.

FIG. 7.

Latent Heat of Total Evaporation of Water, in lb C.H.Us, from Solution containing 1.lb. SO_3

Sensible Heat for Solution containing 1lb. SO_3
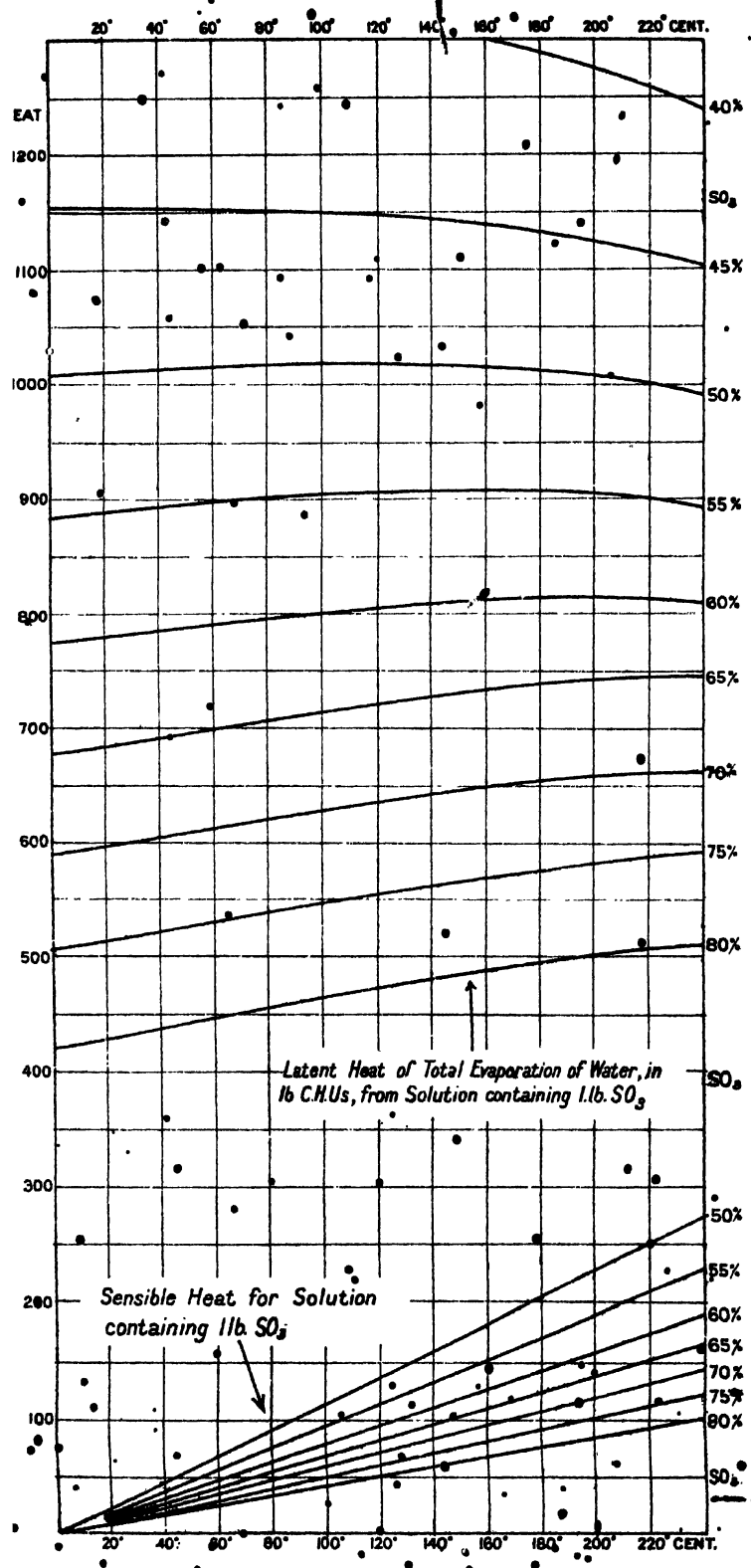
For 1 lb. SO$_3$ this becomes $\frac{42,150}{75} = 562$ C.H.U., whereas Porter's method gave 556 C.H.U. This agreement is good, the difference being slightly over 1 per cent. Henceforward, however, Porter's tables will be reverted to in determining the following heat requirements:---

Heat Requirements.—The concentration of x per cent. H$_2$SO$_4$ to 92 per cent. H$_2$SO$_4$, where x = 65 per cent. to 78 per cent. H$_3$SO$_4$ as in the Gaillard towers, may be tabulated as follows:—

Initial strength of acid.	Heat in calories for a solution containing 1 gm. of SO$_3$.	Heat in C.H.U. for 1 ton of 92 per cent. H$_2$SO$_4$.	Initial strength of acid.	Heat in calories for a solution containing 1 gm. of SO$_3$.	Heat in C.H.U. for 1 ton of 92 per cent. H$_2$SO$_4$.
65	556·0	934,100	72	420·2	706,000
66	536·0	900,500	73	402·0	675,400
67	513·4	862,500	74	385·0	646,800
68	494·0	829,900	75	368·0	618,200
69	474·0	797,000	76	352·0	591,300
70	458·5	770,300	77	337·0	566,200
71	439·0	737,500	78	321·0	539,300

The effect of variation of the final concentration strength with a constant initial feed will now be considered, taking the case of the concentration of 65 per cent. H$_2$SO$_4$ up to x per cent. H$_2$SO$_4$, where x = 92 per cent. to 96 per cent., and the conditions are those which exist in the Gaillard tower.

Final concentration strength.	Initial concentration.	Heat in C.H.U. for 1 ton of product.	Final concentration strength.	Initial concentration.	Heat in C.H.U. for 1 ton of product.
Per cent.	Per cent.		Per cent.	Per cent.	
92	65	934,100	95	65	1,032,900
93	,,	968,200	96	,,	1,066,400
94	,,	1,000,000			

* One ton of coal delivers to the Gaillard furnaces the equivalent of 140,000 cubic feet of producer gas at N.T.P. at a temperature of 300° C. This gas has the average composition—

		Per cent.
CO$_2$	- - - - - -	6·0
CO	- - - - - -	24·0
H$_2$	- - - - - -	8·8
CH$_4$	- - - - - -	2·4
N$_2$	- - - - - -	58·8
		100·0

and a calorific value of 130 B. Th. U. = 72·3 C.H.U.

Heat supplied.—Heat of combustion of 140,000 cubic feet of producer gas, 140,000 × 72·3   10,111,100 C.H.U.

Sensible heat entering furnace, 140,000 × 0·074 × 0·24 × 285   -   -   -   -   -   -   -   708,600 C.H.U.

Total heat   -   -   -   -   -   10,819,700 C.H.U.

(1 cubic foot of gas weighs 0·074 lb. and has a sp. ht. of 0·24.)

Under normal working, say to 9 per cent. of CO_2 in the burnt gas, the volume of air is given by

$$\frac{\text{Vol. air}}{\text{Vol. gas}} = \frac{2·76}{1}$$

Then, weight of air, 140,000 × 2·76 × 0·08 -   -   -   -   -   -   -   30,912 lb.

Weight of gas, 140,000 × 0·074   -   10,360 lb.

Total weight of burnt gases leaving main tower at 220° C. -   -   -   -   41,272 lb.

Heat expended.—Sensible heat in flue gas leaving 220° C., 41,272 × 0·24 × 205 -   -   -   -   -   2,030,600 C.H.U.

Net heat supplied to tower   -   -   -   -   8,789,100 C.H.U.

The coal consumption per 1 ton of 65 to 92 per cent. acid may now be determined.

One ton of 93 per cent. acid requires 934,100 C.H.U. (*see* page 15), and to this must be added the additional heat for—

(*a*) Losses by radiation.

(*b*) Dissociation losses of H_2SO_4 into SO_3, SO_2, &c.

As an approximation, it may be assumed that an additional 20 per cent. of heat will be required, and the heat requirements then become

$$\frac{934,100 \times 120}{100} = 1,120,900 \text{ C.H.U.}$$

But, working to a 9 per cent. CO_2 content in the burnt gases, the available heat per ton of coal for concentration in the main tower is 8,789,100 C.H.U.

The concentration of 1 ton 65 to 92 per cent. H_2SO_4 requires

$$\frac{1,120,900}{8,789,100} = 0·128 \text{ ton of coal.}$$

FIG. 8.

H.M.FACTORY QUEEN'S FERRY

GAILLARD TOWERS.

II

Graph shewing relationships between
I Concentration gradient (End point
92%, Initial point 65-78% H₂SO₄) &
Coal consumption.
II Concentration gradient (End point
92-96%, Initial point 65% H₂SO₄ &
Coal consumption.

COAL CONSUMPTION IN TONS

I

PER CENT H₂SO₄

2260

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H.M. FACTORY QUEEN'S FERRY. GAILLARD TOWERS,

CONSUMPTION
OF COAL
IN TONS.

FIG. 9.

·1600
·1575
·'550
·1525
·1500
·1475
·1460
·1425
·1400
·1375
·1350
·1325
·1300
·1275
·1250
·1225
·1200
·1175
·1150
·1125
·1100
·1075
·1050
·1025
·10

Air Dilution &
Coal Consumption

Graph shewing the relationships
between CO_2 & Coal consumption
& between Air dilution & coal
consumption.
Concentration from 65% to 92%
(With constant dissociation).

CO_2 in burnt gasses &
Coal consumption.

5 6 7 8 9 10 11 12 13 14 15 16 17 % CO_2 IN BURNT GASES

100 150 200 250 300 350 400 450 500 550 600 650 700 VOLS.AIR PER 100 VOLS GAS

2260

H.& D.GRAHAM LTD LITH. LONDON.S.E.

The tabulation can now be extended as follows (Fig. 8) :—

Initial concentration.	Final concentration.	Per cent. CO_2 in burnt gases.	Equivalent fuel consumption.
		Per cent.	
65	92	9	0·1280
66	,,	,,	0·1230
67	,,	,,	0·1175
68	,,	,,	0·1130
69	,,	,,	0·1090
70	,,	,,	0·1050
71	,,	,,	0·1010
72	,,	,,	0·0965
73	,,	,,	0·0920
74	,,	,,	0·0980
75	,,	,,	0·0845
76	,,	,,	0·0807
77	,,	,,	0·0770
78	,,	,,	0·0736
65	93	,,	0·1320
,,	94	,,	0·1365
,,	95	,,	0·1410
,,	96	,,	0·1460

The influence of air dilution on the coal consumption with a constant feed and product, and assuming the dissociation of sulphuric acid to be constant, will now be considered.

Proceeding on the same lines as were used to determine the heat available for concentration with a burnt gas of 9 per cent. CO_2, the following figures are obtained for the special case of 65–92 per cent. concentration. (Fig. 9.)

CO_2 in burnt gases.	Vols. air. Vols. gas.	Coal consumption.	CO_2 in burnt gases.	Vols. air. Vols. gas.	Coal consumption.
17.1	1·06	0·116	8·0	3·24	0·132
9·0	2·76	0·128	5·0	5·64	0·157

The coal consumption of 0·116 is that theoretically obtainable by adding just that quantity of air necessary for complete combustion of the producer gas. It is not contended from this that as high a CO_2 content as possible should be aimed at. It has already been stated that the most suitable furnace temperature to work to is in the neighbourhood of 1,000° C. The conditions militating against working at higher temperatures and CO_2 contents have been pointed out in this connexion. The comparisons noted above showed the distinct economic advantages of working to a CO_2 figure of 9–10 per-cent. as against a low CO_2 figure, say 5 per cent., representing a temperature in the neighbourhood of 600° C.

It should be especially noted that in these comparisons all calculations are based on the work done in the main tower. It has been already mentioned that much of the waste heat from the main tower is caught again in the recuperator as sensible heat, only to be permanently lost to the system, however, in the heat exchange in the recuperator acid coolers.

AIR CONSUMPTION.

The following figures will serve to indicate the quantities of air consumed working to the original scheme, viz., that in which acid is blown down through atomisers into the recuperators as well as into the main tower.

During the month of October 1918, air was supplied to the plant at seven atmospheres pressure, and the actual tonnage of acid charged to the towers was 19,775 tons, say 20,000 tons.

Feed acid charged to main tower -	-	- 20,000 tons.
Feed acid charged to recuperators -	-	- 20,000 × 1½
		= 30,000 tons.
Total amount of acid elevated	-	- 50,000 tons =
		50,000 × 2,240 lbs.

100 lb. acid occupies 1 cubic foot.

Volume of air displaced in cubic feet at atmospheric pressure—

$$\frac{50,000 \times 2,240 \times 7}{100 \times 1} = 7,840,000 \text{ cubic feet of air.}$$

20,000 tons of weak acid yield 14,200 tons of strong acid.

∴. For the concentration of every ton of product the air required is approximately—

$$\frac{7,840,000}{14,200} = 550 \text{ cubic feet.}$$

CONCURRENT VERSUS COUNTER-CURRENT UNITS.

Production Capacity.—On page 14 a comparison has already been made on the question of circuit resistances, and these are reflected in the water-gauge readings.

Under normal working conditions with a feed of acid of 65–66 per cent. and a final concentrated product of 92 per cent. the capacity of a counter-current unit with a 16-inch fan running at 1,400–1,500 r.p.m. varies from 40–45 tons per day.

The capacity of a concurrent unit, however, is much greater. For lower fan speeds the capacity is much increased, and at a fan speed of 1,440 r.p.m. an average figure for a good concurrent unit is 60 tons per diem. It naturally follows that at higher initial feed strengths the capacity is correspondingly increased.

FIG. 10.

H.M. FACTORY — QUEEN'S FERRY.

GAILLARD CONCENTRATORS

DIAGRAM SHEWING PATH OF GASES FROM COMBUSTION CHAMBER TO STACK.

TOWER Nº 3................HOURS ENDING................19................
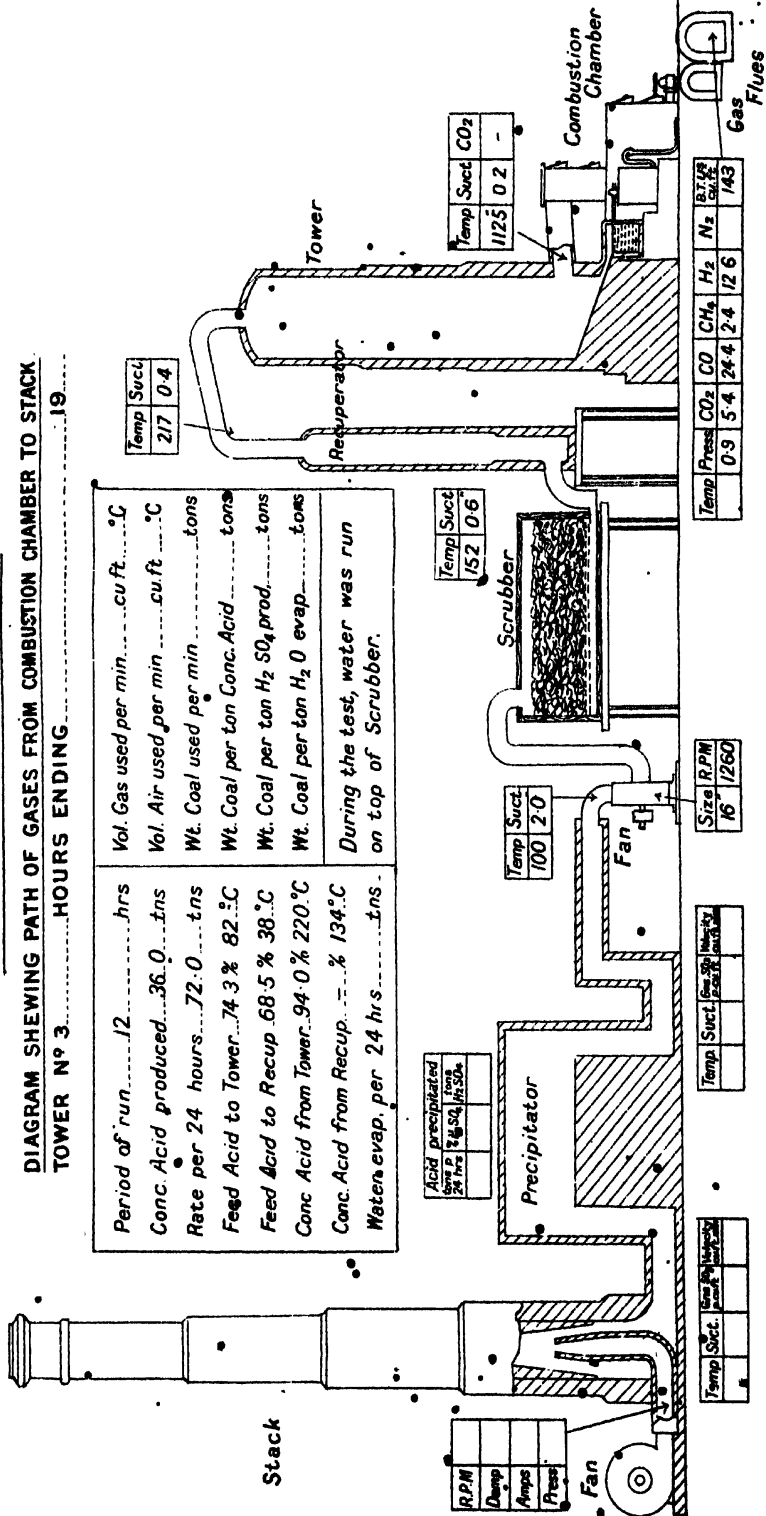
Period of run......12..........hrs	Vol. Gas used per min.......cu ft......°C
Conc. Acid produced...36.0....tns	Vol. Air used per min.......cu ft....°C
Rate per 24 hours...72.0....tns	Wt. Coal used per min.........tns
Feed Acid to Tower...74.3 % 82.°C	Wt. Coal per ton Conc. Acid........tons
Feed Acid to Recup 68.5 % 38.°C	Wt. Coal per ton H₂ SO₄ prod......tons
Conc. Acid from Tower..94.0 % 220.°C	Wt. Coal per ton H₂O evap......tons
Conc. Acid from Recup...—..% 134.°C	During the test, water was run
Water evap. per 24 hrs......tns.	on top of Scrubber.

Stack

Fan

Precipitator

Scrubber

Fan

Recuperator

Tower

Combustion Chamber

Gas Flues

Temp	Suct	CO₂
1125	0 2	—

Temp	Suct
217	0.4

Temp	Suct
152	0.6

Temp	Suct
100	2 0

Size	R.P.M
16	1260

Temp	Press	CO₂	CO	CH₄	H₂	N₂	B.T.U Std. ft.
0.9	0.9	5.4	24.4	2.4	12.6	143	

Temp	Suct	Gas Vel.

Acid precipitated		
tons P	tons	H₂
24 hrs	H₂ SO₄	SO₄

R.P.M
Damp
Amps
Press

Temp	Suct.	Gas Vel.

FIG. II.

H.M. FACTORY — QUEEN'S FERRY.

GAILLARD CONCENTRATORS.

DIAGRAM SHEWING PATH OF GASES FROM COMBUSTION CHAMBER TO STACK

TOWER No. 3. .... HOURS ENDING .... 19 ....

Period of run........12..........hrs.	Vol. Gas used per min......cu.ft.....°C.
Conc Acid produced...32·0...tns.	Vol. Air used per min......cu.ft.....°C.
Rate per 24 hours...64·0....tns.	Wt. Coal used per min.......tons
Feed Acid to Tower.. 74·3% 68°C.	Wt. Coal per ton Conc Acid......tons
Feed Acid to Recup. 69·3% 52°C.	Wt. Coal per ton H₂ SO₄ prod......tons
Conc Acid from Tower 95·0% 220°C.	Wt. Coal per ton H₂O evap......tons
Conc Acid from Recup. 72·3% 132°C.	During the test, water was run on
Water evap per 24 hrs......tns.	top of Scrubber.

Stack.

Fan

Precipitator

Scrubber

Recuperator

Tower

Combustion Chamber

Gas Flues

Fan

| R.P.M. |
| Demd |
| Amps |
| Press |

| Acid precipitated |
| H₂SO₄ |

| Temp. | Suct. | Gas | SO₄ | Velocity |

Size	R.P.M.
16"	1260

Temp	Suct.
107	2·0"

Temp	Suct.
147	0·5"

Temp	Suct.
218	0·4"

Temp	Suct.	CO₂
1125	0·2"	

Temp	Press	CO₂	CO	CH₄	H₂	N₂
	0·8"	4·2	25·8	2·4	12·4	146
218						

B.T.U. cu.ft.
146

A number of tests were made on the first concurrent unit the results of which are set out in the following table :—

Tons.	Initial feed.	Degree of concentration.	Fan speed.
	Per cent.	Per cent.	r.p.m.
77	72·0	93·0	1,260
72	74·0	94·0	1,260
64	74·0	95·0	1,260
100	74·0	91·2	1,440

The first three of these tests were obtained using a 16-inch fan running at 1,260 r.p.m.

These performances were test runs. Owing to the difficulty of keeping the recuperator outlet and fan temperatures down, it was necessary to reduce the rate of production. This was obviously due to the difficulty in obtaining a sufficient supply of acid for the recuperator. Given a plentiful supply of acid available for cooling in the recuperator it can be seen that the production capacity of this unit at a fan speed of 1,800 r.p.m. is well above the 100 ton mark.

Examples of the physical data obtained from the unit are shown in the two diagrams, Figs. 10 and 11.

The capacity of a unit concentrating to a constant concentration product is dependent on the strength of the initial feed. On the basis worked out in a previous section the same heat requirements apply to the following groups :—

(1)　(a)　50 tons 92, per cent. from 65 per cent. feed.
　　　(b)　77 　,,　　　　,,　　　　,,　　　75　　,,　　　　,,
(2)　(a)　60 　,,　　　　,,　　　　,,　　　65　　,,　　　　,,
　　　(b)　92 　,,　　　　,,　　　　,,　　　75　　,,　　　　,,

It is obvious in comparing unit outputs, therefore, that attention must be paid not only to fan speeds and furnace temperatures, but also to initial and final concentrations.

A new type of 21-inch Kestner fan, a sketch of which is shown in Fig. 12, was afterwards introduced in connection with one of the counter-current units. The design was developed by Messrs. Kestner, Ltd., to treat, with a water-gauge of 7 to 8 inches at the fan, a volume of 6,000 cubic feet of gas at 100° C. A test was run on this unit with the fan running at 1,500 r.p.m., with the following results.

The unit is capable of concentrating 70 tons of 92 per cent. per day from a feed of 65 per cent. to 67 per cent. H_2SO_4. Actual determinations of the volume of gases dealt with by the fan during this test were not made owing to the discordant results obtainable. Previous experience with the present available type of anemometer and the unfavourable condition of sudden changes in the direction of motion of the gases prevailing at the fan have shown the futility of obtaining results of any

accuracy. The following method, however, will yield approximately the volume dealt with per minute by the fan when concentrating to this capacity :—

·13 ton of coal is required for concentration of 1 ton 92 per cent. acid from 65 per cent. H_2SO_4 per diem.

1 ton of coal yields 140,000 cubic feet of gas.

∴ ·13 × 140,000 = 18,200 cubic feet gas per 1 ton 92 per cent. acid.

1 volume of gas requires 2·76 volumes of air to produce 9 per cent. of CO_2 in burnt gases.

3·76 volumes of gas and air become 3·6 volumes after combustion.

∴ volume of burnt gas at 100° C. per 1 ton of 92 per cent. acid

$$= \frac{3·6 × 18,200 × 373}{273} = 89,520 \text{ cubic feet at } 100° \text{ C. fan temperature.}$$

Water evaporated in main tower = 0·416 tons.

Steam produced in cubic feet at 100° C.

= 0·416 × 2,240 × 26·75.
= 24,930 cubic feet.

Total volume of gases at 100° C. = (89,520 + 24,930) = 114,450 cubic feet.

To this must be added the maximum of 15 per cent. for air leaks through the system, then

Total volume per day—

= 131,620 cubic feet.

The volume passing through the fan per minute—

$$= \frac{131,620}{1,440} = 91 \text{ cubic feet.}$$

The treatment of 70 tons per day therefore requires 70 × 91 = 6,370 cubic feet per minute at 100° C.

The water-gauge readings through the unit were :—

	Inches.
Furnace - - - - - -	0·25
Tower downtake - - -	1·90
Recuperator inlet - - -	3·40
Recuperator outlet - - -	5·00
Scrubber inlet - - - -	5·10
Scrubber outlet - - - -	8·10
Fan inlet - - - - -	10·10

THE NEW RECUPERATORS AND RECUPERATOR ACID COOLERS.

The fundamental alterations introduced in the new system are shown in Fig. 13, and may be classified as follows :—

(a) Substitution of pumps for eggs in all cases where the elevation of acid is necessary.

FIG. 12

H. M. FACTORY QUEEN'S FERRY.

DIAGRAM OF 21 IN. FAN AT GAILLARD TOWERS.

Suction

Delivery

Delivery

PLAN OF TANKS ETC. ON
TOP PLATFORMS.

Steady Head Tank Feeding
Recuperator Tanks.

OverFlow to Lower Tanks

Recuperator
Feed Tanks

Scrubbers

Scrubbers

PLAN. SHEWING TOP TANKS &
PLATFORMS REMOVED.

Recuperators

Recuperator Launder

Towers

Cakes of
Fum-dr-ylo Acid

Gases to Cottrell

Elevated Tanks
Feeding Tower Sprays

Pumps to
Steady Head

Demitrated Acid
Tanks

OverFlow
Pipe

Scrubber Launder

Lower Tanks, feeding
Elevated Tanks.

Recuperator Feed Tanks

Elevated
Tanks

Tower

Lower
Tanks

Scrubbers

Scrubbers

Gas Ducts

Fan

FIG. 13.
H.M. FACTORY, QUEEN'S FERRY.
PLAN OF GAILLARD CONCENTRATION PLANT
SHEWING ARRANGEMENT OF FEED TANKS
& LINES UNDER THE NEW CONSTRUCTION.

(b) Substitution of a packed "box" type of recuperator for the present tower recuperator.

(c) The installation of 16 recuperator coolers, one to each recuperator, to cool the hot acid delivered from the recuperator.

The general arrangement will now be described.

Acid Circulation.—Acid from the denitrated acid storage tanks gravitates through two 3-inch lead mains to a duplicate set of three Rees Roturbo cast-iron centrifugal pumps situated midway in front of the denitrated acid storage house. These pumps deliver through two 3-inch lead mains, one for each house, to two steady head storage tanks, situated between units 5 and 6 and units 11 and 12 on the spray platfor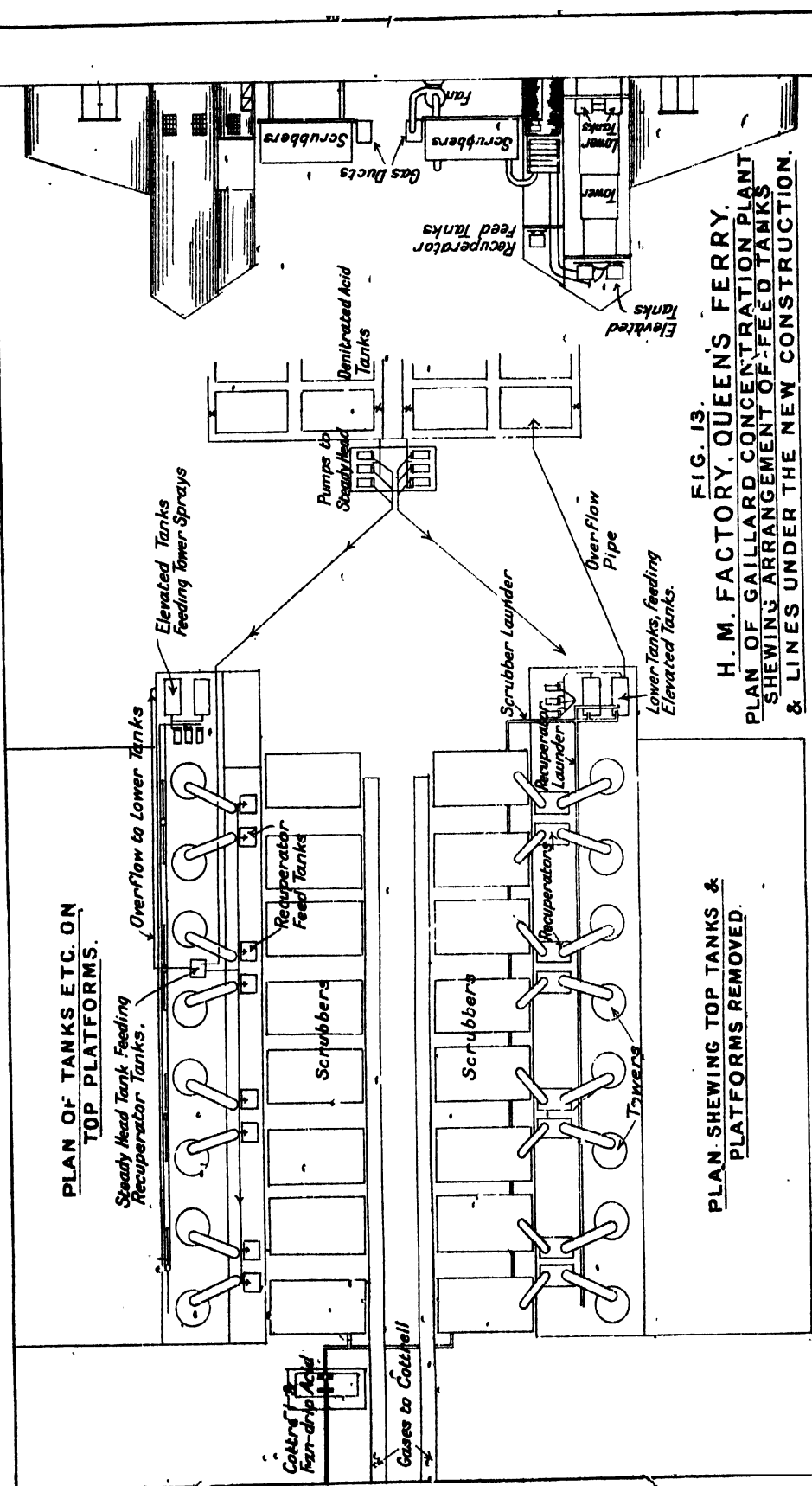ms to the main tower. From this tank acid gravitates to a series of eight small lead-lined tanks grouped in pairs on the same level as the present recuperator top platforms, but between the present recuperators, e.g., between recuperators 7-8, 5-6, 3-4, 1-2. From these eight recuperator tanks in each house acid flows to an open launder from which the acid is fed to 23 distributors and pottery lutes. The acid which collects at the base of the recuperators overflows from the lead saucer into a pipe delivering to a recuperator cooler, from which it passes into a common 4-inch main delivering to a ground level tank at the northern end of each of the two Gaillard houses. The central steady head tanks at the tops of the towers are provided with overflow pipes leading to these ground tanks, which in turn overflow to the weak denitrated acid storage tanks.

In this way all denitrated acid is first passed through the recuperator, and, in addition, arrangements have been made for all fan drips and weak acid received from the Cottrell precipitator to return to the denitrated acid storage tanks. Scrubber acid is made to pass to the ground level tanks like recuperator acid.

The acid from the ground level tanks is the chief supply for the main tower. In each house this acid is elevated by three centrifugal pumps near the tanks to two lead-lined storage tanks, situated immediately above on an extension to the building at the top platform level. These tanks are of dimensions 10 feet by 4 feet 6 inches by 4 feet, and are provided with an overflow to the tanks immediately below. The three lines from the pumps are of 2-inch lead piping.

Three pumps are installed to deliver directly into the main tower through the atomisers. From the pumps two sets of 3-inch cast-iron pipe-lines extend the whole length of the platform and between each pair of towers tee branches are made with 4-inch fullway valves. These are directly connected with both 4-inch mains and extend to the individual tower, where branches with 1-inch fullway valves are connected, and to these 1-inch lead pipes supply acid through the atomiser to the main tower. As a general rule one 4-inch pipe will supply the whole house, but when the spare main is required to be used the 3-inch tee at the reducing piece near the pumps is blanked off from the main and a 3-inch bend fitted between the tee and the spare main.

The "Box" Recuperator.—This consists of a box, 11 feet 3 inches by 6 feet by 10 feet 9 inches high, lined with 12-lb. lead; the walls are

9 inches thick and are constructed of brick. The inlet pipe from the main tower is 24 inches in diameter and within the recuperator is built of acid-proof obsidianite. The outlet pipe is at the top of the recuperator and consists of a 21-inch lead pipe leading off to the scrubber. (Fig. 14.)

Packing.—At the base, the obsidianite pipe opens out at a distance of 1 foot 9 inches from the floor into an arrangement of chequer brickwork. The gases pass through the chequer brickwork and up through a 6-inch layer of acid-proof brick slabs, each 2 feet by 6 inches by 3 inches, arranged with 3-inch spaces, and then through two layers of 6-inch quartz. This is followed by two courses of brick chequer, each 3 inches in thickness, and on these is placed an orderly arrangement of 3-inch pottery rings with spaces arranged vertically. These are continued to a height of 5 feet, and are followed by several courses of 3-inch brick chequer.

The roof bricks forming the cover of the recuperator are 5 feet 1 inch long. The pottery lutes on the top of the recuperator, which are 23 in number, are uniformly distributed, and are supplied by ½-inch bore lead pipes from the distributing launders. These pottery lutes are covered with a lead seal.

The whole recuperator stands on a 30-lb. lead tray, to which is attached a saucer or pan of 30-lb. lead provided with a 3-inch diameter bore lead pipe.

It has since been decided to replace the silicon-iron pipe sections inside the recuperator with obsidianite acid-proof pipes.

Connections from the Main Tower.—From the main tower the offtake is taken from the periphery of the dome to avoid collision with the girders already erected. The whole offtake is of silicon-iron, and is made up of 32 24-inch sections.

The general arrangement is shown diagrammatically in Fig. 15.

Efficiency and Cost of Working.

Table showing Output of Gaillard Towers, Efficiency, and Service Charges for six-monthly Periods.

Period.	Production in tons of H_2SO_4.	Loss.	Average strength of acid obtained.	Loss of H_2SO_4 per Ton.		Services per Ton.	Total per Ton.
				Tons.	Cost.		
	Tons.	Per cent.	Per cent.		£	£	£
1916. June–December -	29,099·5	7·9	90·9	0·086	0·602	0·791	1·393
1917. January–June -	55,312·0	4·0	89·5	0·042	0·294	0·601	0·895
July–December -	58,373·3	2·4	90·7	0·025	0·173	0·811	0·984
January–June -	68,798·9	2·0	92·0	0·020	0·142	1·284	1·426*

* The high figure of £1·426 for total service charges for the six-monthly period ending June 1918 is due to the charge set down for the extensive alterations then in progress, and which include the erection of the new recuperators and recuperator acid coolers.

FIG. 14.

H.M. FACTORY, QUEEN'S FERRY.

SECTION SHEWING PACKING OF NEW RECUPERATORS AT GAILLARD TOWERS.

Inlet

Obsidianite

Outlet

3 in. Chemical Rings

6 in. Quartz

12 lb. Lead

30 lb. Lead
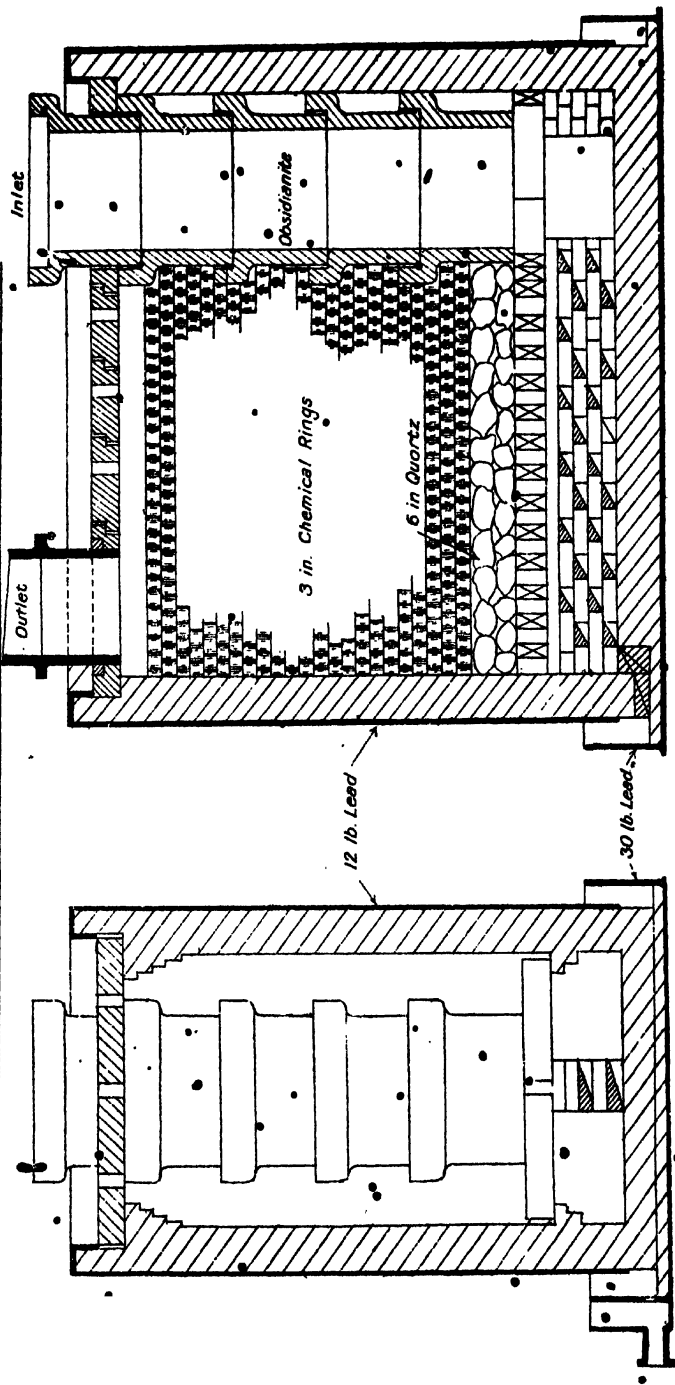
DETAIL OF 3" CHEMICAL RING.

FIG. 15.
— H.M. FACTORY.—QUEEN'S FERRY.—
ELEVATION OF ONE UNIT, SHEWING NEW RECUPERATOR & COOLER
SCALE ⅛ = 1 FT.

Table showing the Output and Efficiency obtained from the Queen's Ferry Gaillard Towers during October 1918.

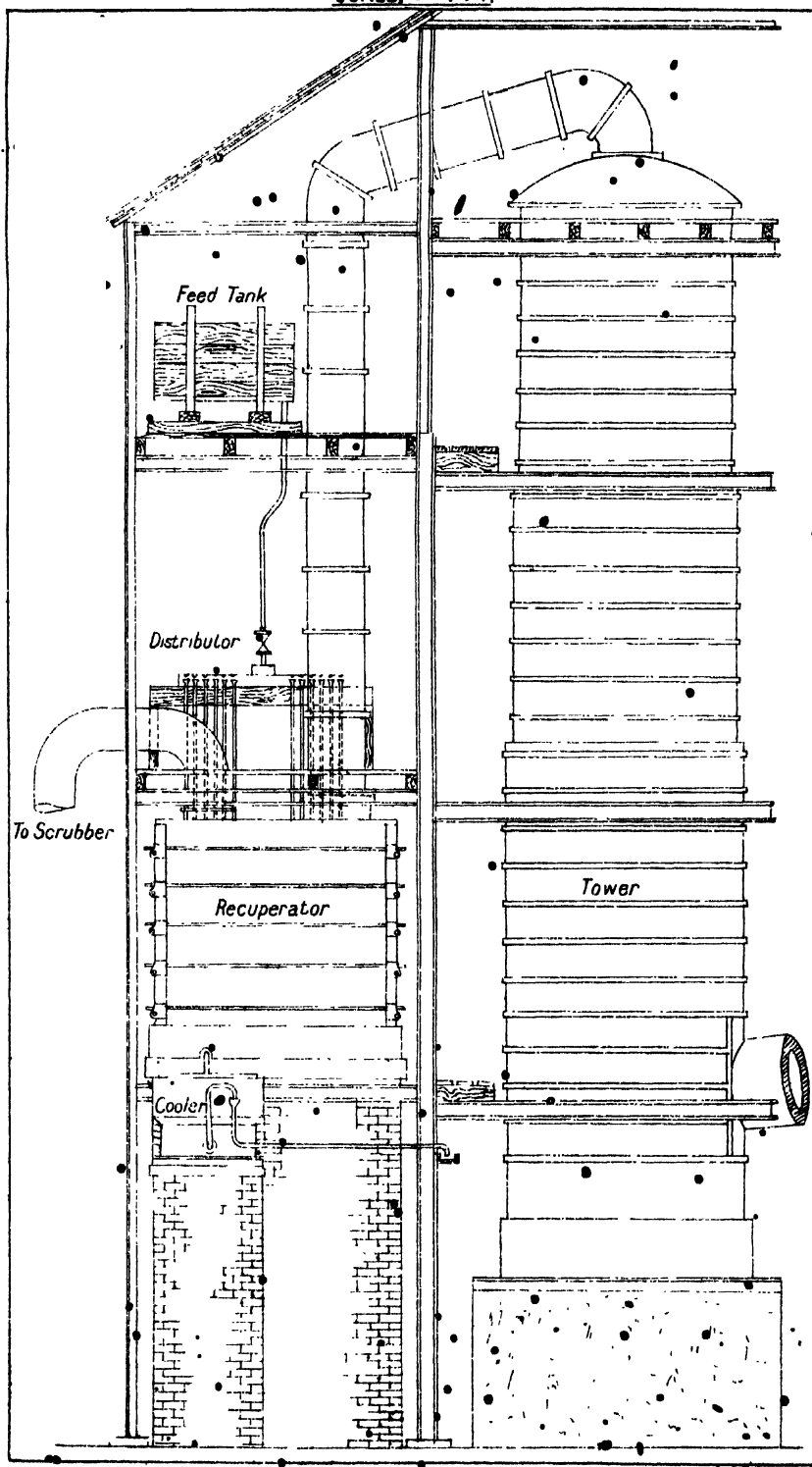| Period.	Production in tons of H_2SO_4.	Strength of concentrate per cent. H_2SO_4.	Strength of feed acid. Per cent. H_2SO_4.	Loss per cent.
1918:—				
October - - - - -	14,116·1	93·5	67·8	1·7
Week ending 5th October - -	2,790·6	93·8	67·8	2·2
„ „ , 12th „ - -	2,612·0	93·9	67·4	1·8
„ „ 19th „ - -	2,735·3	93·4	67·8	2·3
„ „ 26th „ - -	3,138·6	93·3	67·0	0·9
„ „ 2nd November -	2,839·6	92·9	68·3	1·2

A HEAT BALANCE FOR THE GAS PRODUCERS AND GAILLARD TOWERS.

General.—The following results refer to the gas producers and four Gaillard towers working at Gretna.

Object.—To estimate the thermal efficiency of the gas producers and to allocate all the thermal losses.

Result.—Four Gaillard towers producing 11·125 tons of 93·11 per cent. sulphuric acid per hour from 74·7 per cent. sulphuric acid require the consumption of 1·183 tons of coal per hour or 0·1142 tons per ton of H_2SO_4. Under these conditions the total heat (sensible and potential) taken into the system amounts to 15,351,580 C.H.U. per hour. The main items in the expenditure of this heat are given below :—

Item.	Percentage of total heat put into the system.
Loss in producer - - - - - -	13·9
„ „ flue - - - - - - -	10·7
„ „ combustion chamber - - -	7·6
„ „ hot concentrated acid - - -	13·0
„ by radiation and dissociation in tower	8·6
„ in gas main to recuperator - -	0·8
„ „ acid from recuperator - - -	9·5
„ by radiation in recuperator - -	2·0
„ in acid from scrubber - - - -	0·6
„ by radiation from scrubber - -	4·4
„ „ „ between scrubber and exit - - - -	2·1
Leaving in exit - - - - - -	26·8
	100·0

Conclusions.—The efficiency of the producers is good and the losses there, in the flue, and in the combustion chamber are no higher than would be expected.

The greatest preventable heat loss on the Gaillard tower is the heat going away in the hot concentrated acid, which amounts to 20·3 per cent. of the heat supplied to the towers. The recuperator recovers 9·3 per cent. of the heat entering the tower, but this is lost again when the acid from the recuperator passes through the coolers.

If the difficulties involved in a system of heat exchanges for the acids could be overcome, a very large saving of fuel would be effected.

Experimental.—The data upon which this heat balance is based were obtained over a period of 12 hours. From day to day the essential data vary only slightly, but several trial runs were made previously in order to ensure that everything was working smoothly. The run used here was selected as being most representative of the normal working of the two plants.

The temperatures were taken hourly and averaged. The hoppers at the gas producers were carefully calibrated by filling each one on several occasions with weighed quantities of the coal used throughout the run. As gas meters of the requisite capacity were not forthcoming, it was necessary to calculate the volume of the gas produced. This was done by measuring the air going into the producers and calculating on the amount of nitrogen entering as air and on the nitrogen appearing as a percentage of the gas produced. The volume of air was obtained from velocity readings taken in the air flue (20-inch diameter) by means of standard brass Pitot tubes. The air flue was previously calibrated and the current of air found to be moving at a mean velocity on the circumference of a circle, concentric with the flue and of 5-inch radius. Xylene of known specific gravity was used in the gauge.

The water in the steam-air blast was determined by allowing quantities of about 200 cubic feet of the mixture passing into the fuel bed to blow through an apparatus consisting of the following instruments, in the order given :—

(1) A glass tube of wide bore passing into
(2) A soxhlet ball condenser ;
(3) A long liebig condenser ;
(4) A laboratory gas meter fitted with a thermometer.

Both condensers were fitted with bottles to collect the condensed water. This water was weighed and the air leaving the apparatus was taken as saturated. The total weight of water passing into the apparatus could therefore be calculated. Several estimations were made in this way and the method gave consistent results.

Estimations of tar-mist and moisture were made on the gas leaving the producers and entering the Gaillard towers. The tar-mist was filtered out in dry glass-wool contained in a ∪ tube and the water passing over was absorbed in calcium chloride. The glass-wool tube containing the tar was dried in a water bath and the decrease in weight added to the weight of water absorbed by the calcium chloride.

These tests served as a valuable check on the calculated amounts of H_2O and tar present in the gas.

Continuous gas samples were taken from the flue to the Gaillard towers, and the figures given represent averages of these with several snap tests. At the exits of the Gaillards, continuous CO_2, H_2SO_4, and H_2O estimations were made. Throughout the work every care was taken in the sampling of materials.

Data.—All gas volumes are at N.T.P. except where otherwise stated.

Producers working - - 4

Gaillard towers working - 4

Coal used - - - - 1·1833 tons per hour.

Analysis of coal :—

	Per cent.
Carbon - - - - - - - -	- 61·50
Hydrogen - - - - - -	- 4·35
Nitrogen - - - - - - -	- 1·20
Sulphur - - - - - - -	- 1·11
Oxygen - - - - - - -	- 14·44
Ash - - - - - - - -	- 17·40

Moisture in coal used - - 14·42 per cent.

Calorific value of coal (dry sample, determined in bomb calorimeter) - - - - 6,000 C.H.U., or 10,800 B.T.U. per lb.

Ash - - - - - - 2·2 tons per 12 hours.

Combustible matter in ash - 7·1 per cent.

"Blast saturation" temperature 46·5° C.

Atmospheric humidity - - 0·86 lb. per 1,000 cub. ft.

Analysis of gas :—

	Per cent.
CO - - - - - - - -	- 29·4
CO_2 - - - - - - - -	- 2·4
N_2 - - - - - - - -	- 57·6
CH_4 - - - - - - - -	- 1·0
H_2 - - - - - - - -	- 9·6

Calculated gross calorific value of gas - - - - - 80·54 C.H.U. per cub. ft.

Gas made - - - - 113,300 cub. ft. per hour.

Water in gas - - - - 0·354 lb. per 100 cub. ft.

Unfixed carbon in gas leaving producers - - - - 0·098 „

Unfixed carbon in gas entering Gaillards - - - - 0·048 „ „ „

Concentrated acid produced at Gaillards - - - - 11·125 tons per hour per four towers.

Concentrated acid contains 93·11 per cent. of H_2SO_4.

Feed - - - - - 74·70 „ „

Loss in concentration - 1·03 „ „

Acid recovered per hour in each :—

Recuperator - - - 252 lb. of H_2SO_4 as 72 per cent. acid.

Scrubber - - - - 271 lb. of H_2SO_4 as 60 per cent. acid.

Fan - - - - - 11 lb. of H_2SO_4 as 40 per cent. acid.

Acid lost per hour in each exit 60 lb. of H_2SO_4.

Acid circulated in the recuperator - - - - - 2·9 tons per hour.

Strength - - - - - 72 per cent. H_2SO_4.

Volume of exit gases per hour - 124,400 cub. ft. per tower.

CO_2 in exit gases - - - 7·80 per cent.

Temperatures :—

Coal - - - - - - - - 20° C.
Atmospheric - - - - - - 20° C.
Air-steam blast - - - - - - 40° C.
Gas leaving producer - - - - - 600° C.
　„ entering Gaillard combustion chamber 150° C.
Gases entering tower - - - - - 1000° C.
　„ leaving tower - - - - - 220° C.
　„ entering recuperator - - - 210° C.
　„ 　„ scrubber - - - - 140° C.
　„ leaving scrubber - - - - 98° C.
　„ 　„ exit - - - - - 80° C.
Acid at sprays - - - - - - 40° C.
　„ leaving tower - - - - - 220° C
　„ entering recuperator - - - - 45° C.
　„ leaving recuperator - - - - 120° C.
　„ 　„ scrubber - - - - - 90° C.
　„ 　„ fan - - - - - 85° C.

Calculations.—All quantities of heat are given in C.H.U. per hour, all weights of materials in tons or lb. per hour (1 ton = 2,240 lb.), and all gas volumes in cubic feet per hour at N.T.P.

PART I.—GAS PRODUCERS AND FLUE TO GAILLARD TOWERS.

Coal used.

Moisture in coal - - 14·42 per cent.

Coal used in 12 hours - 14·2 tons.
　　　　　= 1·1833 tons per hour.
　　　　　= 1·0125 tons dry coal per hour.
　　　　　= 2,268 lb. dry coal per hour.

Air going into producers.

Velocity in air pipe - - $11 \cdot 51$ ft. per sec. at 20° C.

Area of air pipe - - $2 \cdot 18$ sq. ft.

Volume of air $11 \cdot 51 \times 2 \cdot 18 = 25 \cdot 1$ cub. ft. per sec. at 20° C.

                $= 90,378$ cub. ft. per hour at 20° C.

Moisture in this air.

Moisture in air - - $= 0 \cdot 86$ lb. per 1,000 cub. ft.

1 cub. ft. of air at 0° C. $= 0 \cdot 0806$ lb.

90,378 cub. ft. of moist air at 20° C. contains $90 \cdot 4 \times \cdot 86 = 77 \cdot 7$ lb. of H_2O, which is equivalent to 1,550 cub. ft. of water vapour at 0° C., or 1,660 cub. ft. of water vapour at 20° C.

$90,378 - 1,660 = 88,718$ cub. ft. of dry air at 20° C.

           $= 82,600$ cub. ft. of dry air at 0° C.

           $= 6,650 \cdot 7$ lb. of dry air at 0° C.

Calculation of volume of gas from its nitrogen content.

100 cub. ft. gas contain $57 \cdot 6$ cub. ft. of N_2.

82,600 cub. ft. air contain 65,300 cub. ft. of N_2.

65,300 cub. ft. will be present in—

$$\frac{65,300 \times 100}{57 \cdot 6} = 113,300 \text{ cub. ft. gas.}$$

Steam going into producers.

Air steam blast contains $7 \cdot 0$ gm. H_2O per 100 litres –

$= 8 \cdot 7$ litres H_2O vapour and $91 \cdot 3$ litres dry air

$= 7$ gm. H_2O and 118 gm. dry air.

Dry air going into the producers - - - 6651 lb.

118 gm. of dry air are accompanied by - - 7 gm. of H_2O.

Then 6651 lb. of dry air are accompanied by - 395 lb. of H_2O.

e., 395 lb. of H_2O enter the producer as steam.

Moisture from the air.

82,600 cub. ft. of dry air are accompanied by $77 \cdot 7$ lb. of H_2O.

i.e., of the water entering in the air-steam blast.

$317 \cdot 3$ lb. are obtained from the steam, and

$77 \cdot 7$,,   ,,   ,, atmosphere.

This corresponds to a " blast saturation " temperature of

Carbon content of gas.

29·4 per cent. by volume of $CO = 2·295$ lb. of $CO = 0·9836$ lb. of C per 100 cub. ft.

2·4 per cent. by volume of $CO_2 = 0·296$ lb. of $CO_2 = 0·0337$ lb. of C per 100 cub. ft.

1·0 per cent. by volume of $CH_4 = 0·045$ lb. of $CH_4 = 0·0807$ lb. of C per 100 cub. ft.

         Total carbon per 100 cub. ft. -   -   -   1·0980 lb.

Carbon in 113,300 cub. ft gas. $\dfrac{1·098 \times 113,300}{100} = 1,245$ lb.

Carbon put into producers $\dfrac{2,268 \times 61·5}{100} = 1394·8$ lb.

Ash from producers -   -   2·2 tons per 12 hours.

Taking 7·1 per cent. of combustible matter as carbon, the ash contains   29·12 lb. of carbon per hour.

The distribution of the carbon is then as follows :—

$$\frac{1,245 \times 100}{1,394·8} = 89·40 \text{ per cent. fixed in the gas,}$$

and $\dfrac{29·12 \times 100}{1,394·8} = 2·09$ per cent. lost in the ash,

leaving   8·51 per cent. present, but unfixed, in the gas.

Total heat put into producers.

(a) *Calorific value of coal*— 10,800 B.T.U. per lb. of dry material.
    Dry coal used   -   2,268 lb.
      $2,268 \times 10,800 \times \frac{5}{9} = 13,608,000$ C.H.U.

(b) *Sensible heat in coal*—

    Temperature 20° C.
    Coal contains   - · 14·42 per cent. of moisture.
      2,268 lb. of dry coal and 382 lb. of H_2O.
   $(2,268 \times 0·241 \times 20) + (382 \times 20) = 18,572$ C.H.U.

(c) *Sensible heat in air and steam blast*—

    Temperature 40° C.
    595 lb. of H_2O vapour and 6,650 lb. of air.
$(395 \times 0·454 \times 40) + (6650 \times 0·239 \times 40) = 70,770$ C.H.U.
    Latent heat in steam $= 395 \times 573 = 226,100$ C.H.U.

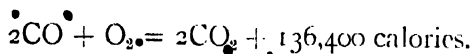*Calorific value of the gas leaving the producers.*

In 100 cub. ft. of gas the combustibles are as follows :—

29·4 cub. ft. of CO = 2·295 lb. of CO.

1·0 cub. ft. of CH_4 = 0·045 lb. of CH_4.

9·6 cub. ft. of H_2 = ·054 lb. of H_2.

Carbon monoxide.

$$2CO + O_2 = 2CO_2 + 136,400 \text{ calories.}$$

2,295 lb. of CO evolve $\dfrac{136,400 \times 2.295}{56}$ = 5,990 C.H.U.

Methane.

$$CH_4 + 2O_2 = CO_2 + 2H_2O + 213,500 \text{ cal.}$$
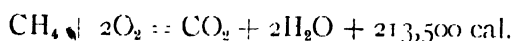
0·045 lb. of CH_4 evolve $\dfrac{213,500 \times ·045}{16}$ = 600·5 C.H.U.

Hydrogen.

$$2H_2 + O_2 = 2H_2O + 138,000 \text{ calories.}$$
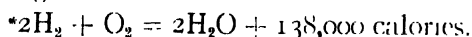
0·054 lb. of H_2 evolve $\dfrac{13,800 \times ·054}{4}$ = 1,863 C.H.U.

Total = 8,053·5 C.H.U.

Gross calorific value of gas = 80·535 C.H.U. per cub. ft., or 145 B.T.U. per cub. ft.

Gross calorific value of 113,300 cub. ft. = 9,140,000 C.H.U.

Sensible heat in gas leaving producers.

Volume of gas 113,300 cub. ft.; Temperature 600° C.

Weights of Gases per Hour.

	Percentage composition of gas by volume.								Cub. ft. per hour.	Lb. per hour.
CO	29·4	-	-	-	-	-	-	-	33,350	2,600
CH_4	1·0	-	-	-	-	-	-	-	1,133	51
H_2	9·6	-	-	-	-	-	-	-	10,890	61
CO_2	2·4	-	-	-	-	-	-	-	2,720	334
N_2	57·6	-	-	-	-	-	-	-	65,140	5,088

The following method, *see* " Producer Gas," by Dowson and Larter, is used throughout in calculating the sensible heat of gases ; Le Chatelier's values are taken.

Mean specific heat of CO at constant pressure between absolute zero and $t°$ C. = $a + b \times (t + 273)$

$$0·2326 + ·0000214 \times (t + 273) \quad - \quad (1)$$

Heat required to raise temperature of 1 lb. of CO from absolute zero to $t_2°$ C. = $a (t_2 + 273) + b (t_2 + 273)^2$ C.H.U. $- (2)$

Heat required to raise temperature of 1 lb. of gas from t_1 to t_2 is the difference between (1) and (2), *i.e.*—

$$a(t_2 - t_1) + b_1(t_2 - t_1)(t_2 + t_1 + 546) \text{ C.H.U.} \quad - \quad - \quad - (3)$$

The mean specific heat between t_1 and t_2 is therefore—

$$a + b(t_2 + t_1 + 546) \quad - \quad - \quad - (4)$$

Using this formula with Le Chatelier's values for a and b, then the mean specific heats for gases between 0° and 600° are—

CO = 0·259, CH_4 = 0·450, CO_2 = 0·245, H_2 = 3·594, N_2 = 0·257.

				C.H.U.
CO 2,600 lb. × 600 × 0·257	-	-	-	401,500
CH_4 51 lb. × 600 × 0·45	-	-	-	13,780
H_2 61 lb. × 600 × 3·594	-	-	-	131,600
CO_2 334 lb. × 600 × 0·245	-	-	-	49,050
N_2 5,088 lb. × 600 × 0·257	-	-	-	784,000
	Total	-	-	1,379,930

Sensible heat of steam in the gas :—

There are 382·2 lb. of water driven off the coal, and this appears as steam in the gas—

382·2 lb. of H_2O in 113,300 cub. ft. = 0·337 lb. per 100 cub. ft.,
or 5·35 gm. per 100 litres.

Tests for moisture in the gas gave results between 5 and 6 gm. per 100 litres, so the steam in the gas is taken as equal to the amount of water driven off the coal.

Latent and sensible heat in water driven off coal :—

The volume of gas is   -   -   -   - 113,300 cub. ft.
The water from the coal is   -   -   - 382 lb.

$$\frac{382 \times 357·5}{18} = 7,590 \text{ cub. ft. of water vapour.}$$

The partial pressure of the steam is-

$$\frac{7590 \times 30}{113300} = 2·01 \text{ inches of mercury.}$$

The boiling point of water and its latent heat under this pressure are 38° C. and 575 C.H.U. respectively.

C.H.U.

Specific heat of steam between 38° C. and
600° C. = 0·553
Sensible heat of water from (20° — 38°)
= 18 × 382   -   -   -   -   -   - 6,880
Latent heat of water = 382 × 575   -   - 219,500
Super heat of steam (38° — 600) = 562
× 382 × 0·553   -   -   -   -   - 118,600

Total   -   -   - 344,980

Efficiency of Producers.

(a) *Efficiency of Gas Production.*—Tar is omitted from this estimate, and the latent and sensible heat of the steam evaporated from the wet coal are not included.

Heat put in.		Heat got out.	
Source.	C.H.U.	Source.	C.H.U.
Calorific value of coal -	13,608,000	Calorific value of gas -	9,140,000
Sensible heat of coal - -	18,572	Sensible heat of gas - -	1,379,900
Sensible heat of air and steam - - - -	70,770		
Latent heat of steam - -	226,100		
	13,923,442		10,519,900

Efficiency $\dfrac{10,159,900 \times 100}{13,923,442} = 75\cdot6$ per cent of heat put into producer.

(b) *Actual Thermal Efficiency.*—The efficiency given under (a) is that which is obtained if all the tar produced were lost. Actually, about 50 per cent. of the tar produced is burnt at the Gaillards. This must be added to the calorific value of the gas both at the producers and at the Gaillards. The loss of tar due to deposition in the flue will be considered as flue loss. In the calculations relating to the carbon content of the gas it was found that $7\cdot98$ per cent. of carbon charged into the producer appeared unfixed in the gas. This is equivalent to $111\cdot3$ lb. of carbon per hour, or $0\cdot098$ lb. per 100 cub. ft., or $1\cdot57$ gm. per 100 litres. Difficulty was found in estimating the tar in the gas, and the results varied between 1 and 2 gm. per 100 litres at the producers and from $0\cdot5$ to 1 gm. per 100 litres at the Gaillards. The calculated figures are therefore used.

Calorific value of the tar :—

$111\cdot3$ lb. of carbon leave the producer as tar.

$$C + O_2 = CO_2 + 97,600 \text{ C.H.U.}$$
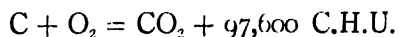
$111\cdot3$ lb. of C evolve $111\cdot3 \times 97,600 = 905,260$ C.H.U.

Sensible heat in tar $= 111\cdot3 \times 0\cdot315 \times 600 = 21,036$ C.H.U.

Amended figures for the heat leaving the producer, including heat in the tar and steam, are as follows :—

	C.H.U.
Source:—	
Calorific value of gas - - - -	9,140,000
Sensible heat of gas - - - -	1,379,900
„ „ steam - - - -	125,480
Latent heat of steam - - - -	219,500
Calorific value of tar - - - -	995,260
Sensible heat of tar - - - -	21,030
Total heat - - -	11,791,170

Actual thermal efficiency of producer :—

$$\frac{11,791,190 \times 100}{13,923,442} = 84\cdot77 \text{ per cent.}$$

Sensible heat in gases entering Gaillard combustion chambers: temperature, 150 C.

Mean specific heat of gases between 0° and 150° :—

$$CO = 0\cdot248 \; ; \; CH_4 = 0\cdot433 \; ; \; CO_2 = 0\cdot207 \; ; \; H_2 = 3\cdot459 \; ;$$
$$N_2 = 0\cdot247.$$

		C.H.U.
CO -	- 2,600 lb. $\times$ 150 $\times$ 0·248 - - -	96,600
CH$_4$ -	- 51 lb. $\times$ 150 $\times$ 0·433 - -	3,310
CO$_2$ -	- 334 lb. $\times$ 150 $\times$ 0·207 - -	10,370
H$_2$ -	- 61 lb. $\times$ 150 $\times$ 3·459 - -	31,650
N$_2$ -	- 5,088 lb. $\times$ 150 $\times$ 0·247 - -	188,600
		330,530

Sensible heat and latent heat in steam in gas at 150°, using the same method of calculation as on page 32, but the temperature of the steam being in this case 150° :—

	C.H.U.
Sensible heat of water = 382 $\times$ 18 - -	6,880
Latent heat of steam = 382 $\times$ 575 - -	219,500
Superheat of steam (38°–150°) = 382 $\times$ 112 $\times$ 0·48 - - - - - - -	20,520
	246,900

Sensible heat of tar in gas :—
Gas contains 55 lb. of carbon as tar :—

55 $\times$ 0·315 $\times$ 150 - - - - - 2,700

Calorific value of tar :—

$$\frac{97,600 \times 55}{12}$$
447,390

Loss in Flue.

Heat leaving producer.		Heat entering combustion chambers.	
Source.	C.H.U.	Source.	C.H.U.
alorific value of gas -	9,140,000	Calorific value of gas	9,140,000
nsible heat of gas -	1,379,900	Sensible heat of gas -	330,520
nsible heat of water and steam.	125,480	Sensible heat of water and steam.	27,400
atent heat in steam -	219,500	Latent heat in steam	219,500
nsible heat of tar -	21,030	Sensible heat of tar -	2,700
alorific value of tar -	905,260	Calorific value of tar	447,300
	11,791,170		10,167,420

C.H.U.

Loss in flue,   11,791,170
                10,167,420

                 1,623,750

$$\frac{1,623,750 \times 100}{11,791,170} = 13 \cdot 7 \text{ per cent. of heat leaving producers.}$$

C.H.U.

Heat in tar at producers   -   -   -   -   926,290
Heat in tar at Gaillards   -   -   -   -   450,000

Loss through deposition of tar   -   476,290

$$\frac{476,290 \times 100}{1,623,750} = 29 \cdot 2 \text{ per cent. of total loss in flue.}$$

Loss in producer.

C.H.U.

Heat put into producers   -   -   -   13,923,400
Heat leaving producers -   -   -   -   11,791,170

                                        2,132,230

$$\frac{2,132,230 \times 100}{13,923,400} = 15 \cdot 3 \text{ per cent. of heat entering producers.}$$

Total loss of heat in producer and flue.

C.H.U.

Heat put into producer -   -   -   -   13,923,400
Heat entering combustion chambers   -   10,167,420

                                         3,755,980

$$\text{Loss in producer and flue} = \frac{3,755,980 \times 100}{13,923,400}$$

$$= 27 \cdot 0 \text{ per cent. of heat entering pro-ducers.}$$

PART II.—GAILLARD TOWERS.

Calculation of amount of air going into combustion chambers.

(a) *Necessary air*—

$$\text{Consider the combustibles in one tower} \begin{cases} 650 \cdot 00 \text{ lb. CO.} \\ 12 \cdot 75 \text{ lb. CH}_4. \\ 15 \cdot 35 \text{ lb. H}_2. \\ 13 \cdot 75 \text{ lb. C as tar.} \end{cases}$$

Carbon monoxide—

$$2CO + O_2 = 2CO_2.$$
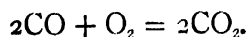
$650 \cdot 0$ lb. of CO require $\dfrac{650 \times 32}{56} = 372$ lb. of oxygen.

Methane—

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$
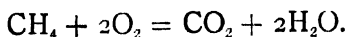
$12 \cdot 75$ lb. of CH_4 require $\dfrac{12 \cdot 75 \times 64}{16} = 51 \cdot 00$ lb. of oxygen.

Hydrogen—

$$2H_2 + O_2 = 2H_2O.$$
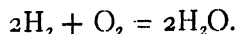
$15 \cdot 25$ lb. of H_2 require $\dfrac{15 \cdot 25 \times 32}{4} = 122 \cdot 00$ lb. of oxygen.

Carbon—

$$C + O_2 = CO_2.$$
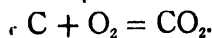
$13 \cdot 75$ lb. of C require $\dfrac{13 \cdot 75 \times 32}{12} = 36 \cdot 67$ lb.

Total oxygen required -   - $581 \cdot 67$ lb.

This volume of oxygen is contained in—

$$\frac{581 \cdot 67 \times 100}{23 \cdot 2} = 2,505 \text{ lb. of air.}$$

2,505 lb. of atmospheric air is accompanied by $26 \cdot 7$ lb. of H_2O.

Burnt with just sufficient air, the products of combustion are as follows:—

Source.	CO_2 lb.	H_2O lb.	N_2 lb.
Combustion of 650·00 lb. CO - - -	1,830·0	—	—
„ „ 42·75 lb. CH_4 - - -	35·1	28·7	—
„ „ 15·25 lb. H - - -	—	137·3	—
„ „ 13·75 lb. C - - -	50·5	—	—
In the gas - - - - - -	83·5	95·6	1,272
From sufficient air - - - - -	—	26·7	1,925

Totals :—

		Cub. ft.
3,197 lb. N_2 - - - - - -		40,980
1,199 lb. CO_2 - - - - - -		9,760
288·3 lb. H_2O - - - - - -		5,720
Total volume - - -		56,460

(b) *Excess air*—

	Cub. ft.
Volume of exit gases from Gaillard (average of readings taken by means of calibrated Pitot tubes, xylene being used in the gauge) - -	124,400
1,658 lb. of H_2O are driven off the acid during concentration, occupying (p. 39) - - - -	32,810
Between the tower and the exit, steam condensed - (This steam appears in the acid from the recuperator.)	5,878
Steam in exit from acid (32,810 — 5,878) - - -	26,932
Products of combustion with sufficient air - -	56,460
Steam from acid - - - - - - -	26,932
Total	83,392

124,400 — 83,390 = 41,010 cub. ft. excess air.

This air is moist and consists of—

35·6 lb. of H_2O and 3,265 lb. of dry air. ·

3,265 lb. of dry air contain $\begin{cases} O_2, 754 \text{ lb.} \\ N_2, 2,511 \text{ lb.} \end{cases}$

Heat in air going into combustion chambers—

Temperature, 20° C.

Air going into each combustion chamber—

(2,505 + 3,265) lb. of air + (26·7 + 35·6) lb. of H_2O,

    5,770 lb. of air + 62·3 lb. of H_2O.

Sensible heat of air at 20° C.   C.H.U.

    5,770 × 0·238 × 20 -   -   -   -   -   -   27,466

Sensible heat in water vapour in air

    62·3 lb. × 0·453 × 20   -   -   -   -   566

Latent heat in steam (partial pressure 0·51 inches

of mercury)

    62·3 lb. × 589 -   -   -   -   -   -   -   36,700

         Total heat going in with air per tower,   -   64,732

               Per four towers   -   -   -   - 258,928

Heat going into the towers from the combustion chambers.—The gases leaving one combustion chamber and entering the tower are as follows :—

Source.	CO_2 lb.	H_2O lb.	N_2 lb.	O_2 lb.
Combustion of CO in gas - - -	1,030·0	—	—	—
„ „ CH_4 „ - - -	35·1	28·69	—	—
„ „ H_2 „ - - -	—	137·3	—	—
„ „ tar „ - - -	50·5	—	—	—
Contained in gas - - - -	83·5	95·6	1,272	—
From sufficient air - - - -	—	26·7	1,925	—
From excess of air - - - -	—	35·6	2,512	754

Total gases leaving combustion chamber—

Temperature, 1,000° C.

Mean specific heat of gases between 0° and 1,000° C.

CO_2 = 279 ; H_2O = 0·612 ; N_2 = 0·265 ; O_2 = 0·233.

                                   C.H.U.

CO_2 -   1,199   × 1,000 × 0·279 -   -   -   -   334,800

H_2O -   323·9 × 1,000 × 0·612   -   -   -   198,300

N_2 -   5,708   × 1,000 × 0·265 -   -   -   -   1,514,000

O_2 -   754   × 1,000 × 0·233 -   -   -   -   175,600

Latent heat in steam in air   -   -   -   -   -   36,700

Latent heat in steam in gas $\dfrac{219,500}{4}$ -   -   -   54,870

       Total heat entering one tower   -   -   -   2,314,270

       Total heat entering four towers -   -   -   9,257,080

Loss in combustion chamber.

Source.	Heat in combustion chamber.	Heat leaving combustion chamber.
	C.H.U.	C.H.U.
Calorific value of gas - - - - - -	9,140,000	—
Sensible heat of gas - - - - - -	330,520	9,257,080
Sensible heat of steam - - - - - -	27,400	—
Latent heat of steam - - - - - -	219,500	—
Calorific value of tar - - - - - -	447,300	—
Sensible heat of tar - - - - - -	2,700	Loss 1,169,270
Total heat going in with air - - - - -	258,930	—
	10,426,350	10,426,350

$$\text{Loss} = \frac{1,169,270 \times 100}{10,426,350} = 11 \cdot 2 \text{ per cent.}$$

C.H.U.

Total heat entering the towers from combustion chambers - - - - - - - - 9,257,080

Heat introduced in feed acid :—
Specific heat of 74·7 per cent. $H_2SO_4 = 0\cdot454$.
Feed acid contains 20,705 lb. of $SO_3 = 33,950$ lb. of 74·7 per cent. acid at 40° C.
Sensible heat in feed acid, $33,950 \times 40 \times 0\cdot454$ - 615,480

Total heat entering tower - - - - 9,872,560

Heat in gases leaving the towers.

In addition to the gases which enter the tower, the following leave it :—

600 lb. of H_2SO_4 as 90 per cent. acid mist.
1,658 lb. of H_2O driven off the acid.

600 lb. of H_2SO_4 as 90 per cent. acid is combined with 66·6 lb. of H_2O, making 666·6 lb. of 90 per cent. acid and leaving 1,591·4 lb. of H_2O free; for four towers this is equal to 6,365·6 lb. of free H_2O.

Latent and sensible heat in water driven off acid.

On page 37 the volume of exit gas from one Gaillard tower, together with the volume occupied by the steam which is driven off the acid, are given as follows :—

Feet.

Volume of gas - - - - - - 124,400
Volume of steam - - - - - 32,810

The partial pressure of steam is-—

$$\frac{32,810 \times 30}{124,400} \quad 7\cdot91 \text{ inches of mercury.}$$

The boiling point of water and its latent heat under this pressure are 66·3° C. and 559 C.H.U. respectively.

Specific heat of steam between 66° and 220° C = 0·496.

	C.H.U.
Sensible heat of water from 40° to 66·3° C., 6,365 × 26·3 - - - - -	167,400
Latent heat of evaporation, 6,365 × 559 - -	3,558,000
Superheat from 66·3° to 220° C., 6,365 × 0·496 × 153·7 - - - - - -	485,200
Total heat in steam from acid - - -	4,210,600

Mean specific heat of gases between 0° and 220° C. :—

CO$_2$ = 0·213, H$_2$O = 0·486, N$_2$ - 0·248, O$_2$ = 0·218.   C.H.U.

CO$_2$ - 1,199 × 220 × 0·213 flue gas - -	56,160
H$_2$O - 323·9 × 220 × 0·486 ,, - -	34,600
N$_2$ - 5,728 × 220 × 0·248 ,, - -	311,200
O$_2$ - 754 × 220 × 0·218 ,, - -	36,160
Latent heat in steam in air, flue gas - - -	36,700
Latent heat in steam in gas ,, - - -	54,870
H$_2$SO$_4$, 666·6 lb. of 90 per cent. acid, 666·6 × 220 × 0·38, acid mist - - - - -	55,740
(This acid is considered as being carried over mechanically from the tower, and is not credited with latent heat.)	
Total heat, excluding heat in steam from acid, per tower - - - - -	585,430
Total, excluding heat in steam from acid, per four towers - - - - -	2,341,720
Heat in steam from acid - - - -	4,210,600
Total heat leaving in gases - - -	6,552,320

The heat of concentration.

Following the method used by Porter in "The Thermal Properties of Sulphuric Acid and Oleum," this figure is arrived at as follows :—

Data. {
Concentrated acid - 11·125 tons of 93·11 per cent. H$_2$SO$_4$.

Feed acid - - 74·7 per cent. H$_2$SO$_4$.

2,400 lb. of H$_2$SO$_4$ as 90 per cent. acid are carried over from the tower as acid mist.
}

∴ Feed = (11·125 tons of 93·11 per cent. H$_2$SO$_4$ + 2,667 lb. of 90 per cent. H$_2$SO$_4$), as 74·7 per cent. H$_2$SO$_4$ = 34,260 lb.

Temperature of feed acid at sprays - - 40° C.

Temperature of concentrated acid leaving tower - - 220° C.

To find the total heat of concentration :—

93·11 per cent. of H_2SO_4 - = 76·01 per cent. of SO_3.
90·00 „   „   „   - = 73·40 „   „
74·70 „   „   „   - = 61·01 „   „

11·125 tons = 24,920 lb.

11,125 tons of acid containing 76·01 per cent. of SO_3 contain 18,942 lb. of SO_3.

(1) 18,942 lb. of SO_3 as 61 per cent. SO_3 solution at 40° C., concentrated to 76·01 per cent. SO_3 at 220° C.

From Porter's tables :—

(a) For 1 lb. of SO_3 (first method).

C.H.U.

Heat to concentrate from 61 per cent. to 76·01
per cent. at 40° C. (767 − 504) - - - 236
Heat to raise temperature from 40° to 220° C. - 89

352

(b) For 1 lb. of SO_3 (second method).

Heat to raise 61 per cent. SO_3 solution from
40° to 220° C. - - - - - - - 140
Heat to concentrate from 61 per cent. to 76·01
per cent. at 220 C. (799 − 571) - - - 228

368

Average of two methods, 360 C.H.U.

Heat required for 18,942 lb. = (18,942 × 360) = 6,819,120 C.H.U.

(2) 2,400 lb. 90 per cent. H_2SO_4 = 1,960 lb. SO_3.

1,960 lb. of SO_3 as 61 per cent. SO_3 solution at 40° C. to be oncentrated to 73·4 per cent. SO_3 solution at 220° C. :—

(a) For 1 lb. of SO_3 (first method).

C.H.U.

Heat to concentrate from 61 per cent. to 73·4
per cent. at 40° C. (767 − 547) - - - 220
Heat to raise temperature from 40° to 220° C. - 96

316

(b) *For 1 lb. of SO₃ (second method).*

                                                            C.H.U.

Heat to raise 61 per cent. SO₃ solution from
    40° to 220° C. -   -   -   -   -   -   140

Heat to concentrate from 61 per cent. to 73·4 per
    cent. at 220° C.   (799 — 610) -   -   -   189
                                                         ———
                                                          329

Average of two methods, 323 C.H.U.

Heat required for 1,940 lb. of SO₃ = 1,940 × 323 = 633,000 C.H.U.

Heat of concentration = (1) 6,819,120 + (2) 633,000 = 7,452,120 C.H.U.

The heat necessary to concentrate acid from 74·7 to 93·1 per cent. is thus found to amount to 7,452,120 C.H.U. per hour for the four towers, according to Porter's tables.

Heat in hot concentrated acid, temperature 220° :—

    Sp. heat of 93·11 per cent. H_2SO_4 -   ·366

    11,125 tons 93·11 per cent. H_2SO_4 24,930 lb.

    24,930 × 220 × ·366 -   -   -   -   2,007,360 C.H.U.

The following figures given under "Heat balance of four Gaillard towers" show the amount of heat entering and how it is distributed. The amount expended in actual concentration will be represented by—

                                                            C.H.U.

Heat left in the concentrated acid   -   -   2,007,360

  „   „   „ steam carried off   -   -   4,210,600

  „   „   „ acid mist -   -   -   -   222,960
                                                   —————————
                                                   6,440,920

Any heat absorbed in dissociation of H_2SO_4 into SO₃ and H_2O should be added to the above figures, but there is no evidence that SO₃ as such left the tower, as the acid mist was recovered as 90 per cent. H_2SO_4 immediately after leaving the tower.

Consequently, 6,440,920 C.H.U. represent the amount of heat required to concentrate the acid according to measurements which were actually carried out, whereas 7,452,120 C.H.U. represented the amount of heat required, according to Porter's tables.

It will be interesting to see if future measurements of the distribution of heat in concentrating sulphuric acid show closer agreement with the amount found by the tables.

Heat Balance of Four Gaillard Towers.

The following heat balance is compiled from the measurements actually made:—

Heat entering four towers (source).	C.H.U.	Distribution of heat (source).	C.H.U.	Per cent.
In furnace gases	9,257,080	Heat in concentrated acid.	2,007,360	20·3
In feed acid	615,480	Heat in steam	4,210,600	42·6
		„ acid mist	222,960	2·3
		„ flue gas	2,118,760	21·5
		Radiation and dissocia-tion.	1,312,880	13·3
Total	9,872,560	Total	9,872,560	100·0

A check on the consumption of gas, including tar, is provided by the percentages of CO_2 in the final exit gases.

Volume of exit gases per tower - 124,400 cub. ft.

Average CO_2 content in exit gases - 7·8 per cent.

Volume of CO_2 in exit gases - - 9,703 cub. ft.   (1).

CO_2 from combustion of calculated weight of gas per tower : —

1,030·0 lb. of CO_2 from - - 655·45 lb. of CO.

35·1 lb. of CO_2 from - - 12·75 lb. of CH_4.

83·5 lb. of CO_2 present in gas.

50·4 lb. of CO_2 from - - 13·75 lb. of C. as tar.

Total - 1,199·0 lb. of CO_2 - - - 9,740 cub. ft. of CO_2 (2).

37 cub. ft. of CO_2 are produced by the combustion of 108 cub. ft. of gas.

C.H.U.

Calorific value of 108 cub. ft. of gas (including tar) - - - - - - - approx. 9,180

Sensible heat of 108 cub. ft. of gas (including tar) - - - - - - - - 1,700

10,880

Heat going into one tower from combustion chamber

$$= \frac{9,249,160}{4} = 2,312,290 \text{ C.H.U.}$$

∴ Maximum error in the difference between the amount of gas calculated as delivered to the tower and the amount of gas calculated

as being burnt in the combustion chamber from the percentage CO_2 in the exit gases is only

$$\frac{10,880 \times 100}{2,312,290} = 0.47 \text{ per cent.}$$

Heat in gases going into the recuperators.

Temperature, 210° C.

The gases are taken to be of the same composition as those leaving the tower, but at 210° C. instead of 220° C., one recuperator alone is considered.

Mean specific heat of gases between 0° and 210° C.—

$$CO_2 = 0.212, \quad H_2O = 0.484, \quad N_2 = 0.248, \quad O_2 = 0.218.$$

		C.H.U.
CO_2 - $1,199 \times 210 \times 0.212$	- - - -	53,380
H_2O - $523.9 \times 210 \times 0.484$	- - - -	32,930
N_2 - $5,708 \times 210 \times 0.248$	- - - -	297,200
O_2 - $75 \times 210 \times 0.218$	- - - -	34,500
Latent heat in steam in air	- - - - -	36,700
Latent heat in steam in gas	- - - - -	54,870
H_2SO_4, 666·6 lb. of 90 per cent. acid :		
$666.6 \times 210 \times 0.38$ -	- - - -	53,200

Total heat, excluding heat in steam from acid,
per tower - - - - - - - -   562,780

Total heat, excluding heat in steam from acid,
per four towers - - - - - - -   2,251,120

Heat in steam from acid - - - - -   4,179,400

Total heat entering recuperators - - - -   6,430,520

Loss in main to recuperators.

Heat in gases leaving towers - - - - -   6,552,320

Heat in gases entering recuperators - - -   6,430,520

Loss in main - - - - - - - -   121,800

$$\frac{121,800 \times 100}{6,552,320} = 1.86 \text{ per cent.}$$

Up to the present, steam in the gases from four different sources has been considered, viz. :—

  (1) Steam in the gas (driven off the coal in the producer).

  (2) Steam in the air drawn into the combustion chambers.

  (3) Steam due to combustion of H_2 and CH_4 in the gas.

  (4) Steam driven off the acid in the process of concentration.

These amounts of steam have been formed at different temperatures and consequently contain different amounts of latent heat. In the recuperator, scrubber and fan various quantities of water are deposited and in order to deduct the correct amount of heat, it is necessary to obtain an average value for the latent heat of the whole of the steam present.

C.H.U.

(1) Steam in the gas, 302·2 lb.; latent heat - - 219,500

(2) Steam in air to combustion chambers, 251 lb.;
    latent heat, 36,700 × 4 - - - - - 146,800

(3) Steam in the gas as product of combustion, 664 lb.; the gross calorific value of the gas has been taken and this steam therefore cannot be credited with latent heat.

(4) Steam driven off the acid, 6,365·6 lb.; latent heat - - - - - - - - - 3,558,000

Total, 7,662 lb. of steam containing latent heat - - - - - - - 3,924,300

Then 1 lb. of steam contains latent heat $\dfrac{3,924,300}{7,662\cdot8} = 514.$

All the steam from now onwards will be taken as having a latent heat of 514 C.H.U. per lb.

The distribution of the H_2SO_4 and H_2O leaving the tower.

Leaving one tower in the exit gases are 600 lb. of H_2SO_4 and 1,982 lb. of H_2O.

The 1,982 lb. of H_2O in the exit gases are derived from—

1,658 lb. of H_2O from the acid.

324 lb. of H_2O from the combustion chamber.

600 lb. of H_2SO_4 as 90 per cent. acid is combined with 66·6 lb. of H_2O.

These amounts of H_2SO_4 and H_2O are distributed through the scrubbing system, &c., as follows:—

Recovered in recuperator - 252 lb. of H_2SO_4 - 98 lb. of H_2O.
 „ „ scrubber - 271 „ „ „ - 181 „ „ „
 „ „ fan - - 11 „ „ „ - 17 „ „ „
Lost in exit - - - 66 „ „ „ - 1,686 „ „ „

Heat in gases leaving the recuperators.

Temperature, 140° C.

Consider one recuperator: the gases leaving are—

1,199 lb. of CO_2
5,708 „ „ N_2
754 „ „ O_2

(600 — 252) = 348 lb. of H_2SO_4 as 7½ per cent. acid (assuming the acid to be in equilibrium with the acid in the recuperator) (1,982 − 98) = 1,884 lb. of H_2O.

The 348 lb. of H_2SO_4 being present as 72 per cent acid are combined with 135 lb. of H_2O.

$\therefore$ Steam present as free $H_2O = (1,884 - 135) = 1,749$ lb. and $(348 + 135) = 483$ lb. of 72 per cent. H_2SO_4.

Mean specific heat of gases between 0° and 140° C.

$CO_2 = 0.206$, $N_2 = 0.247$, $O_2 = 0.217$, $H_2O = 0.473$.   C.H.U.

CO_2 -	- $1,199 \times 140 \times 0.206$ - - -	34,600
N_2 -	- $5,708 \times 140 \times 0.247$ - - -	197,500
O_2 -	- $754 \times 140 \times 0.217$ - - -	22,900
H_2O -	- $1,749 \times 140 \times 0.473$ - - -	115,600
Latent heat ... $1,749 \times 514$	- - - -	899,000
H_2SO_4 -	483 lb. of 72 per cent. acid of specific heat 0.473 ... $483 \times 140 \times 0.473$	32,000

Total heat leaving one recuperator - - -	1,301,600
Total heat leaving four recuperators - -	5,206,400
Total heat entering recuperators - -	6,430,520

Heat to be accounted for   1,224,120

Acid passed through one recuperator.

This quantity is 2.9 tons of 72 per cent. H_2SO_4 of specific heat 0.473 (p. 28).

Temperature of acid entering $= 45°$ C.

Temperature of acid leaving $= 120°$ C.

$\therefore$ Heat put into acid $= 2.9 \times 2,240 \times 75 \times 0.473 = 230,400$.

For four recuperators, $230,400 \times 4$ - - -   921,600

Loss in recuperator - - - - - -   302,520

$\dfrac{302,520 \times 100}{6,430,520} = 4.7$ per cent. of the heat entering the recuperators.

Heat in acid leaving recuperators.

(a) Sensible heat in feed acid ; (b) heat added in recuperator.

(a) $2.9 \times 2,240 \times 45 \times 0.473 = 138,400$.

For four recuperators ... $138,400 \times 4$ - -   553,600

(b) Heat added in four recuperators - - - -   921,600

Heat in acid leaving recuperators - -   1,475,200

Heat in gases leaving scrubbers.

Temperature, 98° C.

Consider one scrubber ; gases, &c., leaving are—

$$1,199 \text{ lb. of } SO_2.$$
$$5,708 \text{ ,, ,, } N_2$$
$$754 \text{ ,, ,, } O_2.$$
$$(348 - 271) = \quad 77 \text{ ,, ,, } H_2SO_4 \text{ as 60 per cent. acid.}$$
$$(1,884 - 181) = 1,703 \text{ ,, ,, } H_2O$$

77 lb. of H_2SO_4, being present as 60 per cent. acid, is combined with 51·3 lb. of H_2O, making 128·3 lb. of 60 per cent. acid and leaving $(1,703 - 51·3) = 1,651·7$ lb. of free H_2O.

Mean specific heat of gases between 0° and 98° C.—

$CO_2 = 0·202$, $N_2 = 0·246$, $O_2 = 0·216$, $H_2O = 0·466$.   C.H.U.

CO_2	- - $1,199 \times 98 \times 0·202$ - - - -	23,750
N_2	- - $5,708 \times 98 \times 0·246$ - - - -	137,600
O_2	- - $754 \times 98 \times 0·216$ - - - -	15,960
H_2O	- - $1,652 \times 98 \times 0·466$ - - - -	75,500
Latent heat	$1,652 \times 514$ - - - - -	850,000
H_2SO_4 . . . 128·3 lb. of 60 per cent. acid of specific heat 0·54 . . . $128 \times 98 \times 0·54$ - - -		6,780

Total heat leaving one scrubber	-	-	1,109,590
Total heat leaving four scrubbers	-	-	4,438,360
Total heat entering scrubber -	-	-	5,206,400

Heat to be accounted for	- - - -	768,040

Heat in acid leaving scrubber.

Temperature, 90° C.

452 lb. of 60 per cent. acid, $452 \times 90 \times 0·54 = 21,980$.

For 4 scrubbers - - - - - - - 87,920

Loss in scrubbers - - - - - 680,120

$$\text{Loss} = \frac{680,120 \times 100}{5,206,400} = 12 \text{ per cent. of the heat entering the scrubbers.}$$

Heat leaving in exit.

Consider one exit : gases, &c., leaving are :—

$$1,199 \text{ lb. of } CO_2.$$
$$5,708 \quad ,, \quad N_2.$$
$$754 \quad ,, \quad O_2.$$
$$(77-11) = 66 \quad ,, \quad H_2SO_4 \text{ as 40 per cent. acid.}$$
$$(1,703-17) = 1,686 \quad ,, \quad H_2O.$$

66 lb. of H_2SO_4 as 40 per cent. acid are combined with 99 lb. of H_2O, making 165 lb. of 40 per cent. H_2SO_4 and leaving $(1,686-99)$
$$= 1,587 \cdot 6 \text{ lb. of free } H_2O.$$

Mean specific heat of gases between 0° and 80° C.

$CO_2 = 0 \cdot 201$, $N_2 = 0 \cdot 245$, $O_2 = 0 \cdot 215$, $H_2O = 0 \cdot 463$.

CO_2: $1,199 \times 80 \times 0 \cdot 201$ - - - -	19,290
N_2: $5,708 \times 80 \times 0 \cdot 245$ - - - -	111,900
O_2: $754 \times 80 \times 0 \cdot 215$ - - - -	12,970
H_2O: $1,587 \times 80 \times 0 \cdot 463$ - - - -	58,800
Latent heat: $1,587 \times 514$ - - - -	816,000
H_2SO_4: 165 lb. of 40 per cent. acid—	
$165 \times 80 \times 0 \cdot 67$ - - - - -	8,840

Total heat in gas leaving one exit -	1,027,800
Total heat in gas leaving four exits -	4,111,200
Heat leaving four scrubbers - - -	4,438,360
Heat to be accounted for - - -	327,160

Heat in acid thrown out by fan.

Temperature, 85° C.

28 lb. of 40 per cent. acid of specific heat $0 \cdot 67$.

$28 \times 85 \times 0 \cdot 67$ (from one exit) 1,595	
(from four exits) - - -	6,380
Loss between scrubber and exit - -	320,780

$$\text{Loss} = \frac{320,780 \times 100}{4,438,260} = 7 \cdot 2 \text{ per cent. of the heat leaving the}$$
scrubber.

Heat leaving in exits - - - - 4,111,200

Heat losses incurred at the different stages.

	C.H.U.	See Page
At the producer - - - - -	2,132,230	35
In the main flue - - - - -	1,623,750	35
In the combustion chamber - -	1,169,270	39
In the hot concentrated acid - -	2,007,360	42
In dissociation in tower } - - -	1,312,880	43
In radiation from tower }		
In gas main to recuperator - -	121,800	44
In acid from recuperator - - -	1,475,200	46
In radiation from recuperator - -	302,520	46
In acid from scrubber - - -	87,920	47
In radiation from scrubber - - -	680,120	47
In radiation between scrubber and exit - - - - - -	320,780	48
In final exit - - - - -	4,111,200	—
	15,345,030	

The total heat put into the system is :—

Heat put into producer - - -	13,923,440	33
Heat in air to combustion chambers -	258,928	38
Heat in original feed acid - -	615,480	39
Heat in acid from recuperator - -	553,600	46
	15,351,448	

SOME NOTES ON THE MECHANISM OF CONCENTRATION.

The following tests and considerations help to give a clearer idea of what occurs during the concentration process by the Gaillard system.

An analysis of an acid drip from the waste gas outlet neck on No. 2 tower of the Gretna plant showed the sample to be remarkably strong, and only 1 per cent. lower in H_2SO_4 content than the acid entering the sludge box. The laboratory figures were as follows :—

Sp. Gr.	H_2SO_4.
1·836 - - - - - -	93·1 per cent.

A sample of the feed acid to the tower was taken at the same time from the sprays, and the analysis found to be :—

Sp. Gr.	H_2SO_4.
1·699 - - - - - -	76·7 per cent.

No. 2 tower on the above date was fitted with a 21-inch Kestner fan running at 1,200 r.p.m., and the temperature of the gases in the tower outlet as recorded by pyrometer was 215° C. From the above it is evident that a remarkably strong acid leaves the tower by the

fume outlet on its way to the recuperator. It is remarkable that in spite of the close proximity of weak acid, *in the form of spray*, to the point at which the sample of "drip" acid was taken, that the latter should have such a high H_2SO_4 content. This peculiarity was confirmed by taking samples of similar leaks on other towers, the particulars of which are recorded in Table I.

The results tabulated are not quite so outstanding as in the case of No. 2 tower, the only one running with a 21-inch fan, all others being provided with 16-inch, but, nevertheless, sufficient in themselves to indicate the least expected conditions at such a point in the system. It is most unlikely that, from a chemical point of view, the acid falling down the tower is dissociated into SO_3 and H_2O, the SO_3 passing up the tower and later picking up a little H_2O to make a strong acid; and still more unlikely from a mechanical point of view that some of the concentrated drops should journey upwards, by reason of draught, in complete isolation through drops of weaker acid. It would seem that the only feasible explanation is that sulphuric acid of, say, 75 per cent. strength, when *sprayed* into an atmosphere at the temperatures recorded above is almost instantaneously concentrated to the region of 90 per cent., in spite of that atmosphere containing water vapour which must necessarily be fairly large in quantity in the vicinity of the sprays. The water driven off from the weak acid will remain in the form of water vapour and the concentration of the acid be maintained so long as the temperature is sufficiently high to overcome the affinity of the acid for the water. The above indicates the ground on which the acid mist referred to on page 39 is taken as 90 per cent. sulphuric acid. The water content and the temperature of the atmosphere, combined with the fineness of the spray, are the three factors which control the degree and rapidity of this concentration. The moment the temperature is lowered beyond the requisite degree at the existing vapour pressure of the acid, the water is reabsorbed and weaker acid results. This is precisely what occurs in the recuperator, and no matter how the recuperator is controlled, an acid leaving it stronger than that in the vicinity of the sprays cannot be obtained under present working conditions.

Strength of the Acid entering the Recuperator.—During a period when this plant was producing 90 per cent. H_2SO_4, the temperature required at the top of the tower being so low (180-190° C.) rendered it possible to run the recuperator without feed from external sources to cool down the gases before entering the scrubber. Table II. shows figures obtained. Here it will be seen that the acid drawn over from the tower has been reduced in strength to a figure very little below that of the feed acid to the tower itself. The figures show slight lagging due to the amount of acid required to fill the saucer. The samples were taken at the overflow lip of the saucer. The table shows, however, that the higher the outlet temperature of the gases, the higher the H_2SO_4 content of the acid running from the recuperator. The figures represent fairly well the type of acid trapped in the recuperator under ordinary working conditions with external feed.

Experiments on the Recuperator as an "Acid Catcher."—Experiments were carried out to ascertain the amount of acid which was drawn over from the tower and trapped in the recuperator by taking stock in the recuperator system before and after each experiment. These were conducted when the concentration was increased from 90 per cent. to 92 per cent. from the towers. Particulars of these experiments are given in Table III.

Make of Acid in Scrubber.—Whilst carrying out the experiments recorded in Table III. the amount of scrubber acid collected was recorded at the same time and the results obtained are shown in Table IV. These two tables (III. and IV.) show the amount of acid drawn over from the tower to be fairly considerable, not taking into account the amount of mist passing into the air up the exit stack.

A portion of the water removed from the acid in the tower is again reabsorbed, as will be seen from Table VI. The latter shows the increased amount of water reabsorbed when the plant is running on a small output, which is explained by the fact that the heat units passing from the tower in such a case are insufficient to carry the water, in the form of vapour, over the large surfaces to which the gases are unavoidably exposed.

Deductions as to the nature of the Gases.—It may be safely assumed that in the gases leaving the tower at the outlet numberless spheroids of relatively strong acid are suspended in the atmosphere of super-heated steam diluted with waste gases (CO_2, &c.) from the furnace, plus excess air. As previously stated, the idea of free SO_3 being present as a gas at this point is most unlikely, nor is it any more likely that the spheroids are of varying strength at steady and existing temperatures, &c., because the figures obtained show a sharp and distinct relationship between the gravity of the tower outlet drip and the temperatures. The only conclusion, therefore, is that each and all the spheroids are approximately of the same H_2SO_4 content. If anything, the drip shows a slightly lower concentration than that occurring actually in the centre of the gas flow, due to the fall in temperature on the walls of the outlet pipe. Local and slight differences no doubt occur in the concentration of the solid bodies of the mist, due to eddies causing pockets of colder gas.

It is clear that these suspended globules or spheroids of sulphuric acid absorb water, and so become weaker as the temperature is lowered. A very casual inspection of the experiments on the "dry" recuperator shows this, and also the fact that it is impossible to feed the recuperator with acid and run it off at a concentration equal to that of the drip, and, finally, that water is reabsorbed to the degree shown in Table VI. As the gases pass on through the recuperator to the scrubber and thus become still cooler, it is found that those spheroids which escaped being trapped absorb more water from their atmosphere, when the scrubber arrests some of them, and yields an acid weaker than that leaving the recuperator. This absorption of water continues in a similar manner throughout the system until the escape of gases from

the plant into the air, where a mist consisting of homogeneous spheroids, and not an odd few strongly acid among weaker acid spheroids, is obtained. What is wanted is a more rapid elimination of these spheroids from their atmosphere. The spheroids, when exposed to surface friction, are de-electrified by reason of neutralization of charges and lose their individuality. The tower outlet pipe on this plant accounts for most of the acid collected in the recuperator rather than the recuperator itself.

Table I.

Date.	Tower.	Temperature of tower outlet °C.	Sp. gr. of spray feed.	Per cent. H_2SO_4.	Sp. gr. of outlet drip.	Per cent. H_2SO_4.
20/6/17	6	215	1·694	76·7	1·807	87·8
		217	1·676	74·7	1·808	87·9
		218	1·668	74·5	1·808	87·9
		214	1·695	76·7	1·805	87·7
		204	1·667	74·4	1·794	86·2
		207	1·670	74·7	1·798	86·7
25/6/17	6	210	1·660	73·8	1·811	88·4
		210	1·662	73·8	1·806	87·7
		205	1·665	74·2	1·800	86·9
		210	1·641	72·2	1·803	87·2
		210	1·648	72·8	1·804	87·4
		204	1·662	73·8	1·799	86·8
		216	1·678	75·3	1·818	89·8
27/6/17	6	215	1·696	76·9	1·810	88·2
	5	209	1·694	76·7	1·805	87·5
	5	218	1·701	77·2	1·807	87·8
29/6/17	6	207	1·672	74·7	1·796	86·4
		212	1·690	76·3	1·815	89·1
		197	1·694	76·7	1·812	88·5
		193	1·660	73·8	1·800	86·9
		207	1·682	75·5	1·813	88·7

The above percentages of H_2SO_4 are taken from Lunge's gravity tables, and are considered sufficiently accurate for the purpose.

Table II.

Experiments on "Dry" Recuperator.

Date.	Temperature of recuperator outlet °C.	Sp. gr. of acid leaving.	Per cent. H_2SO_4.	Sp. gr. of spray feed.	Per cent. H_2SO_4.
19/6/17	145	1·672	74·7		
	147	1·710	78·1	1·710	78·0
	146	1·729	79·8		
	140	1·731	79·9	1·718	78·8
	136	1·653	73·4		
	143	1·689	76·3	1·684	75·6
	142	1·705	77·6		

Date.	Temperature of recuperator outlet °C.	Sp. gr. of acid leaving.	Per cent. H_2SO_4.	Sp. gr. of spray feed.	Per cent. H_2SO_4.
19/6/17	144	1·700	77·2	1·694	76·3
	145	1·706	77·6		
	147	1·702	77·3	1·670	74·7
	143	1·745	81·1		
	138	1·744	81·0	1·684	75·5
	136	1·743	80·9		
	145	1·743	80·9		
	145	1·744	81·0		
	147	1·744	81·0		
	148	1·743	80·9	1·694	76·7
	148	1·748	81·4		
	148	1·748	81·4		
	142	1·749	81·5	1·670	74·7

All the percentages of H_2SO_4 recorded above are taken from Lunge's gravity tables, and considered sufficiently accurate for the purpose.

Table III.

Make of Acid in Recuperators (Towers producing 92 per cent. Sulphuric Acid).

Date and Time.	Stock in recuperator system in tons of H_2SO_4.			Production on towers in tons of H_2SO_4.	Percentage recovered in recuperator.
	Before.	After.	Make.		
24 hours ending:—					
29/6/17, 2.15 p.m.	26·5	37·4	10·9	199·0	5·5
4/7/17, 11.0 p.m.	19·6	27·9	8·3	143·1	5·8
9/7/17, 4.15 p.m.	20·2	26·9	6·7	149·3	4·5
16/7/17, 11.15 p.m.	19·7	30·7	11·0	180·2	6·1

Table IV.

Scrubber Acid make (Towers producing 92 per cent. H_2SO_4).

Date and Time.	Collected in scrubber tanks.	Sp. gr. of acid collected.	Production from towers in tons of H_2SO_4.	Recovery as scrubber acid in tons of H_2SO_4.	Percentage recovered in scrubbers.
24 hours ending:—					
29/6/17, 2.15 p.m.	7·9	1·630	199·0	5·63	2·8
4/7/17, 11.0 p.m.	9·1	1·631	143·1	6·37	4·5
9/7/17, 4.15 p.m.	9·3	1·624	149·3	6·56	4·4
16/7/17, 2.15 p.m.	6·3	1·633	180·2	4·51	2·5

Table V.

Showing Total Acid trapped by Recuperator and Scrubbers.

Date and Time.	Production from towers in tons of H₂SO₄.	Tons H₂SO₄ trapped by		Total.	Percentage on production.
		Recuperator.	Scrubber.		
24 hours ending :—					
29/6/17, 2.15 p.m.	199·0	10·9	5·6	16·5	8·3
4/7/17, 11. 0 p.m.	143·1	8·3	6·4	14·7	10·3
9/7/17, 4.15 p.m.	149·3	6·7	6·6	13·3	9·9
16/7/17, 11.15 p.m.	180·2	11·0	4·5	15·5	8·6

Table VI.

Showing the Amount of Water charged to the Tower and reabsorbed in the Recuperator and Scrubber.

Date and Time.	Sulphuric acid charged to towers in tons of H₂SO₄.	Equivalent feed at 75 per cent. H₂SO₄.	Weak sulphuric acid trapped in recuperator.	Per cent. H₂SO₄.	Weak sulphuric acid trapped in scrubber.	Per cent. H₂SO₄.	Water expelled from towers.	Water reabsorbed in recuperator and scrubber.	Percentage of water reabsorbed.
		Tons.	Tons.		Tons.		Tons.	Tons.	
24 hours ending :—									
29/6/17, 2.15 p.m.	199·0	265·3	14·6	74·6	7·9	71·3	50·6	3·5+2·3 =5·8	11·5
4/7/17, 11. 0 p.m.	143·1	190·8	11·1	74·6	9·1	71·3	35·8	2·8+2·7 =5·5	15·4
9/7/17, 4.15 p.m.	149·3	190·1	8·9	7·5	9·3	70·1	36·1	2·2+2·7 =4·9	13·6
16/7/17, 11.15 p.m.	180·2	240·1	14·6	75·1	6·3	71·4	44·4	3·6+1·8 =5·4	12·2

SECTION 2.

GILCHRIST CONCENTRATION PLANT.*

General Outline of Plant.—The Gilchrist concentration plant at Queen's Ferry was fed exclusively with weak sulphuric acid recovered from the denitrated spent acids resulting from the nitration of cellulose.

Figs. 17 and 18 show the general arrangement of the plant, which consists of a combustion chamber, saturex, cooler, tower, feed tank to tower, scrubber or filter tower, feed tank to scrubber, and fan which draws the gases through the plant and delivers them into the flue whence they are aspirated through a Cottrell precipitator, and thence discharged through the stack into the atmosphere.

Each tower is fed from an overhead lead-lined feed tank, 10 feet by 15 feet by 4 feet 6 inches, into which the acid is raised, through a lift of $73\frac{1}{2}$ feet, either by four Kestner elevators, each capable of raising three tons per hour, or by one of three 2-inch belt-driven Douglas pumps. The acid is fed by syphon feed from these tanks to three distributing launders running across the top of the tower. The acid overflows from eight lips on each side of these into lead funnels leading down to the lutes in the lead cover.

At the time when the production of nitrocellulose ceased, two special 12-inch impeller Rees Roturbo pumps were being installed to deliver the feed acid direct from the lead vats to the feed tanks at the top of the towers.

The acid is concentrated as it flows through the packing of the tower and delivers into a pan or saturex, where further concentration is effected, finally being delivered through coolers to the storage tanks as concentrated acid. The gases are led from the main tower through a quartz packed scrubber to a 21-inch Kestner fan, and thence to the stack.

Capacity of Plant.—Two independent units were installed, each capable of concentrating 70 short tons of $93\cdot5$ per cent. sulphuric acid from $65\cdot5$ per cent. acid, or 35 short tons of 97 per cent. sulphuric acid from $65\cdot5$ per cent. acid, using, in both cases, 162,000,000 B.T.U. per 24 hours, or approximately 1,000,000 cubic feet of producer gas.

Furnace.—This consists of a firebrick structure, sheathed in steel. The gas is led from the main producer flues to the furnace by two gas flues, 2 feet by 3 feet, controlled by valves, and enters the combustion chamber through any of the four 6-inch by 12-inch gas ports, expanding to 12 inches by 18 inches after admixture with the primary air. The admittance of the air for combustion is controlled by mush-

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* The patent rights of this plant are controlled by The Chemical Construction Co., Charlotte, N.C., U.S.A.; the representatives in Britain are Messrs. Huntington and Heberlein, Westminster.

room ports at the front of the furnace. The combustion chamber, which measures 8 feet by 11 feet by 5 feet 3 inches, and which is surmounted by a false arch, over which the secondary air is admitted, is fitted with the necessary explosion doors and sight holes.

The products of combustion enter an 8 ft. × 4 ft. 6 ins. × 11 ft. upcast which is filled with chequer brickwork, and are delivered to the saturex by a cross connecting flue measuring 4 ft. 6 ins. × 5 ft.

Saturex.—The inside dimensions of this are 37 ft. 7½ ins. long × 9 ft. wide, the whole structure being raised on a concrete foundation 9 ft. above ground level so as to give the necessary gravity flow to coolers and tanks. The concrete is protected by 6-lb. sheet lead.

The saturex consists of a pan 18 inches deep, of 20-lb. lead, which is lined with three layers of 2-inch acid-proof tiles set in silicate cement. The firebrick arch to the saturex is fitted with four baffle arches, which deflect the hot gases from the furnace on to the surface of the acid. The whole structure is bound with the necessary buck stays, the brickwork containing cavities to take up expansion. The sludging outlets and run-off are fixed so that a depth of 7 inches of acid remains in the saturex.

A certain amount of circulation of the acid in the saturex is secured by two 28-feet silicon-iron spigot and socket pipes, connected to the compressed air main, and having ⅜-inch perforations at distances of 6 inches.

The concentrated acid overflows from the saturex into a brick-lined collecting launder, from which it delivers to any of five lead coolers through a silicon-iron run-off pipe.

Coolers.—The acid leaves the saturex at a temperature of 250° C., and each cooler is capable of cooling 100 tons per day from this temperature down to 35° C. Each cooler is made of 16-lb. lead, and is 3 feet 5 inches in diameter by 4 feet 4½ inches deep, fitted with a water-jacket for the top 30 inches. There are three cooling coils of 1½-inch lead pipe, consisting of 14 turns each, 15, 22, and 29 inches in diameter respectively.

Main Tower.— The base of the main tower rests in the same lead pan as the saturex, and is 11 feet square (inside measurement) and 47 feet 3 inches high. The base is lined with acid-proof tiles, as in the case of the saturex, the packing of the tower resting on seven arches which are sprung from the sides of the tower. The tower is built of acid-proof bricks set in special American cement, the walls being 1 foot 6 inches thick, with a 4½-inch inner wall lined with acid-resisting tiles extending to a height of 14 feet. The walls are bonded every 4 feet vertically and horizontally, and the tower is tied by rods and corner angles every 3 feet of its entire height.

The tower packing is arranged as follows:—

     (a) 14 feet of chequer brickwork (3-inch spaces).
     (b) 7 feet 10 inches of chequer brickwork (2-inch spaces).
     (c) 10 feet of 4-inch quartz.
     (d) 4 feet 3 inches of 3-inch pottery rings.

The gases pass from the tower into the scrubber by a 36-inch off-take of 12-lb. lead stiffened by lead-covered iron bands. This contains a "60" Gaillard spray, through which it was the original intention to spray water to cool the gases. While quite effective from the point of view of cooling, a water spray is uneconomical in that it increases the concentration load, and the attempt to spray weak acid into the off-take, instead of water, has proved quite successful.

The free and wetted Surface of the Tower, with the mean Velocities of the Gases and their reaction times.

(a) *Free space in the main tower.*

Packing.	Free space.	Total volume.
	Cub. ft.	Cub. ft.
1. Bottom layer - - - - - - -	44·6	100·8
2. First layer of 3-inch staggering - - - -	619·0	1,589·0
3. Second layer of 3-inch staggering - - -	466·9	1,087·0
4. 4-inch quartz layer - - - - - -	622·9	1,381·0
5. Layer of 3-inch pottery ring packing - - -	317·6	725·0
Total - - - -	2,071·0	4,882·0

This corresponds to a total free space in the tower of :—

$$\frac{2,071 \times 100}{4,883} = 42\cdot4 \text{ per cent.}$$

As the reaction time begins in the packing, the free space of the arched basement (really part of the saturex) is not included, nor is the space at the top over the rings.

(b) *Total wetted surface in the main tower.*

Sq. ft.

1. Wetted surface in layers of brickwork with 3-inch interspaces - - - - - - - 6,099
2. Wetted surface in layers with 2-inch interspaces - 5,346
3. Wetted surface in layers with 4-inch quartz - 12,830
4. Wetted surface in layers with 3-inch pottery rings - - - - - - - - 23,380
5. Wetted surface in sides of tower - - - 1,826

Total wetted surface - - - - 49,481

(c) *Free cross-sectional area of the main tower.*

The free cross-sectional area of 4-inch coke is 9·5 per cent. of the total cross-sectional area (see page 88).

Free cross-sectional area of main tower is—

$$9\cdot5 \times \frac{121}{100} = 11\cdot5 \text{ sq. ft.}$$

(d) *Velocity of gases in the main tower.*

This is derived from :—

V_1 = velocity in tower.

V_2 = velocity in off-take from tower

(page 60) = $11 \cdot 53$ ft. per sec.

C_1 = free cross-section of tower = $11 \cdot 5$ sq. ft.

C_2 = free cross-section of off-take from

tower = $7 \cdot 7$ sq. ft.

$$\frac{V_1}{V_2} = \frac{C_2}{C_1}.$$

$$\therefore \frac{V_1}{11 \cdot 53} = \frac{7 \cdot 1}{11 \cdot 5}, \text{ and } V_1 = \frac{7 \cdot 1 \times 11 \cdot 53}{11 \cdot 5} = 7 \cdot 1 \text{ ft. per sec.}$$

(e) *Reaction time in the main tower.*

This is derived from :—

$$\frac{\text{Free space in tower}}{\text{Volume of gases per second}} = \frac{2,071}{11 \cdot 5 \times 7 \cdot 1} = 25 \cdot 4 \text{ seconds.}$$

Scrubber.—This rests on a 15-lb. lead pan, and is 31 feet 6 inches high with 18-inch walls of acid-resting bricks, and a $4\frac{1}{2}$-inch inner wall rising to a height of 13 feet 3 inches; a lining of $1\frac{1}{2}$-inch tiles is carried up to the top of the scrubber. The internal cross-section is 15 feet $1\frac{1}{2}$ inches by 12 feet $10\frac{1}{2}$ inches at the base, increasing to 15 feet $10\frac{1}{2}$ inches by 13 feet $7\frac{1}{2}$ inches above the top of the inner wall. The structure is bound by tie-rods and corner angles as in the main tower.

The packing rests on chequer brickwork, so arranged as to give a free gas exit to the fan, and consists of the necessary layers of 10-inch and 6-inch quartz to carry the main filling of 2-inch quartz, the total packing weighing about 300 tons.

Two "60" Gaillard sprays are fixed into the top of the dome, and water was at one time sprayed down these for cooling and scrubbing purposes. The sprays are now fed by weak acid from the same feed pipe as the spray on the main tower off-take (*vide supra*).

The scrubber acid is delivered to the scrubber acid tank through 24 acid ports, each $4\frac{1}{2}$ inches by 3 inches and issues into an internal launder.

The free and wetted surface of the scrubber, with the mean velocities of the gases and their reaction times.

(a) *Free space in the scrubber.*

	Free space.	Total volume.
	Cub. ft.	Cub. ft.
1. Base section - - - - -	44·30	701·70
2. 6-inch to 10-inch quartz - - - -	29·28	64·97
3. 2-inch quartz in basal section - - -	847·00	1,754·00
4. 2-inch quartz in top section - - -	1,308·00	2,708·00
Total - - - -	2,626·18	5,228·67

Hence the free space in the scrubber is 50·22 per cent.

(b) *Total wetted surface in the scrubber.*

	Sq. ft.
1. Bottom layer of 6-inch to 10-inch quartz -	588·9
2. Middle layer of 2-inch quartz - - -	30,870·0
3. Top layer of 2-inch quartz - - - -	51,040·0
4. Area of sides of scrubber - - - -	1,710·0
Total wetted surface - -	84,208·9

(c) *Free cross-sectional area of the scrubber.*

This is 9·5 per cent. of the total cross-sectional area, viz. :—

$$\frac{13 \times 15 \times 9\cdot5}{100} = 18\cdot5 \text{ sq. ft.}$$

(d) *Velocity of gases in the scrubber.*

As in the case of the tower :—

V_1 = velocity in scrubber.

V_2 = velocity in off-take from scrubber

(page 60) = 49·27 ft. per sec.

C_1 = free cross-section of scrubber - 18·5 sq. ft.

C_2 = free cross-section of off-take from

scrubber = 2·4 sq. ft.

Then, $\dfrac{V_1}{49\cdot27} = \dfrac{2\cdot4}{18\cdot5}$, and V_1 is $\dfrac{49\cdot27 \times 2\cdot4}{18\cdot5} = 6\cdot4$ ft. per second.

(e) *Reaction time in the scrubber.*

$$\frac{\text{Free space in scrubber}}{\text{Volume of gases per second}} = \frac{2,620}{18\cdot5 \times 6\cdot4} = 22\cdot2 \text{ seconds.}$$

Fans.—Each unit is fitted with one 21-inch Kestner high-pressure fan, of the same type as that already described in connection with the Gaillard towers. Trouble was experienced with these fans, and a 16-inch fan has been installed as a stand-by, the fume main being arranged to permit of this arrangement. The fans deliver through a 21-inch main into the Cottrell precipitator flue,? feet by 2 feet 6 inches, this being so graded as to drain any condensed acid back to the scrubber launder.

Cottrell Precipitators.—Up to the time when the plant was closed down, the fumes were passed straight from the fans to the stack, but the final arrangement included further scrubbing in the chambers of a Cottrell precipitation plant. The latter is similar in design to that erected for the Gaillard's towers, but on a smaller scale.

It consists of two independent chambers, 30 feet 1½ inches long by 5 feet wide by 5 feet 6 inches deep. There are 96 discharging electrodes, 4 feet 2⅜ inches long, and 40 receiving electrodes, 2 feet wide

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by 5 feet long, provided for each chamber. The stack is a 9 feet by 100-feet brick chimney on the Prat system, as at the Gaillard plant. (See Section III., page 67.)

General Conclusions.—The most serious trouble experienced in connection with the Gilchrist plant has been the excessive wear and tear on the base of the tower and saturex. The temperature of the acid in the saturex causes the tiles to expand and lift, thus forming channel ways through which the acid percolates to the lead base. In a short time this is eaten through, and the concrete foundation is attacked. Whenever a leakage of this kind occurs it necessitates taking up the whole of the tiling and renewing the whole or part of the lead work. Careful control of the temperatures of the furnace and the acid in the saturex decreases the trouble, but does not entirely overcome it. For instance, No. 1 unit worked well for a period of five months, with a furnace temperature never exceeding 850° C. Yet when it was shut down for overhaul, it was found necessary to renew the lead work completely.

The sludging up of the units is another difficulty. The sludge contained in the feed acid settles in the saturex, and is sufficient in amount to necessitate sludging out each unit once a month, the whole of the saturex by that time being full of sludge. This is not a simple matter. Even when no repairs are required, the unit has to be thoroughly cooled down and drained before the saturex is washed out. It is not possible at present to state definitely whether or not any accumulation of sludge in the packing seriously reduces the free cross-section of the tower.

Physical Data.—Fig. 18 gives the general physical data in connection with the Gilchrist plant, and also shows the average daily working of a single unit.

Velocities, Volumes, and Temperatures of Gases.

Position.	Anemometer readings.	Velocity, ft. sec.	Cub. ft. per sec.	Diameter of pipes.	Temperature o° C.
				Ft. in.	
Exit from gas producers	0·265	71·23	170·90	2 0	700° C.
Top of main entering combustion chamber.	0·045	11·31	7¢·97	3 0	135° C.
Offtake from tower {	0·050	12·64 } Mean	89·35	3 9	150° C.
	0·050	10·43 } 11·53	89·37	3 0	150° C.
Offtake from scrubber {	0·760	46·79 } Mean	109·98	1 9	105° C.
	0·950	51·76 } 49·27	124·47	1 9	100° C.
	1·150	56·80	136·60	1 9	98° C.
Offtake from fan {	0·145	19·80	99·50	1 9	85·5° C.
	0·153	20·15	100·10	1 9	80° C.
Brick flue to Cottrell precipitator. {	0·040	10·40	83·51	3 0	45° C.
	0·038	9·63	77·42	3 0	50° C.

Radiation Surface.

	Sq. ft.
Black steel front and sides of furnace - - - -	294·5
Brickwork of furnace - - - - - - -	528·0
Cross-flue { 1. Brickwork - - - - - -	690·0
{ 2. - - - - - -	93·7
Brickwork of saturex - - - - - -	570·0
„ main tower - - - - -	2,835·0
„ scrubber - - - - -	2,117·4
Total - - - -	7,128·69

Steel casting - - - - - - - -	388·2
Brickwork - - - - - - - -	6,740·4
Total - - - -	7,128·69

The following figures represent the averaged results of a series of temperature records :—

Temperature of exterior of furnace $\begin{cases} (1) & 64°\ C. \\ (2) & 48°\ C. \\ (3) & 33°\ C. \end{cases}$ 48° C.

Top of saturex brickwork	- - (4)	44° C.
Base of main tower	- - - (5)	41° C.
Top of main tower	- - - (6)	24° C.
Base of scrubber	- - - (7)	34° C.
Top of scrubber	- - - (8)	24° C.

Average Working Conditions.

The figures below show the conditions obtaining for an average day's working :—

Amount of feed acid to main tower	- - 131·45 tons.
Strength „ „ „	- - 70·3 per cent.
Temperature . „ „ .	- - 23° C.
Amount of concentrated acid produced	- 78·94 tons.
Strength „ „	- - 93·8 per cent.
Temperature „ „ „	- - 258° C.
Amount of acid run into the scrubber	- - 21·75 tons.
Strength „ „ „	- - 48·46 per cent.
Temperature „ „	- - 36° C.
Amount of acid delivered by the scrubber	- 47·3 tons.
Strength „ „ „ „	- 57·2 per cent.
Temperature „ „ „	- 79° C.
Temperature at main tower offtake	- 117° C.
„ fan	- - - - 100° C.
„ base of stack	- - - 63° C.

Amount of SO_3 passed up the stack = 0·72
    tons SO_3 - - - - - - - 0·91 per cent.
Temperature of lead fume duct from fan   - 85° C.
Quantity of coal used - - - - - 7·51 tons.
Air temperature - - - - - - 8° C.
Acid in effluent as SO_3 - - - - - 1·34 tons.

Thermal Value of Producer Gas.

1 ton coal - - - - - - 140,000 cub. ft. gas.
Specific heat of gas - - - - - 0·25.
Temperature of gas entering com-
    bustion chamber - - - - 295° C.
Mass of 1 cub. ft. of producer gas - 0·078 lb.
∴ Sensible heat of 1 cub. ft. - - 0·078 × 295 × 0·25
                         = 5·75   C.H.U.
Heat of combustion of 1 cub. ft. of
    producer gas - - - - - 72   C.H.U.
∴ Thermal value of 1 cub. ft. of
    producer gas - - - - - 77·75 C.H.U.
Hence thermal value of 1 ton of coal - 77·75 × 140,000 C.H.U.
∴ Thermal value of 7·51 tons of
    coal - - - - - - - 7·51 × 77·52 × 140,000
                         = 81,748,453 C.H.U.

FIG. 18.

— H. M. FACTORY — QUEEN'S FERRY. —

GILCHRIST CONCENTRATOR.

INDEX TO GENERAL PHYSICAL DATA.

Gas Flue

Combustion Chamber

Cross Flue

B

C

Saturex

Coolers D

Feed Tank

Ma

E

F

Feed to Scrubber
1 Ton per hour

G

Scrubber

H

21 in Fan
920 R.P.M

Square Flue

J

Precipitator

K

Stack
L

Stack Fan
580 R.P.M.

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Index	Plant	Temp deg C	Pressure + or - inches	Velocity Ft per sec	Make tons per hr	Composition CO₂	CO	CH₄	H₂	N₂	O₂
						CO₂	CO	CH₄	H₂	N₂	O₂
											%
A	Producers	294°	+1.1 in.	71.23 ft.		7.8	2.1	2.2	6.9	62.1	12.3
B	Cross Flue	790°	+0.9 in.			7.8	2.1				
C	Saturex overflow	258°				93.8% H₂ SO₄					
D	Coolers	23°			3.1 tons	93.8% H₂ SO₄ @ 23°C.					
E	Main Tower Top	120°	-0.46 in	11.46 ft.	3.15 tons	70.3% H₂ SO₄ @ 23°C.					
F	Main Tower Bottom	235°				88.9% H₂ SO₄					
G	Scrubber	104°			2.1 tons	57.2% H₂ SO₄ @ 79°C.					
H	Fan	101°	-1.87 in	51.75 ft.		Total acidity as SO₃ 1.37 gms per 100 litres.					
J	Square Flue	85°	see Graph for same	20.02 ft.	too small to measure						
K	Precipitator										
L	Stack	45°	+0.59 in	10.01 ft.		33.0% H₂ SO₄ @ 62°C. Total acidity as SO₃ 0.32 gms per 100 litres.					

SECTION 3.

COTTRELL PRECIPITATION PLANT.*

General Principles of Electrical Precipitation.—When a gas in an ionised condition passes through an electrostatic field, its ions begin to travel at a high velocity in the direction of one or other of the electrodes responsible for the field. Furthermore, if the electrodes are charged to a sufficiently high potential, they become the ionising agents, as well as the source of the propelling force. The highly charged gaseous ions, in passing from the electrode at which they received their charge to the electrode of opposite sign, bombard any solid or liquid particles in their path, imparting to them a charge of like sign, with the result that they, too, begin to travel toward the electrode of opposite polarity.

The rate of ionisation by any electrode, which is equivalent to its rate of silent discharge, depends not only upon its potential, but also upon its form. A flat surface is least efficient, and a point or edge most efficient, from the point of view of ionisation. By making one of the electrodes a sharp point or edge, or a thin wire, and keeping the other a flat surface, a greater stress will be set up in the vicinity of the first, giving rise to more rapid ionisation in the case of that electrode.

The terms "discharge electrodes" and "receiving electrodes" are used in practice to distinguish between the two types. The electrical discharge is arranged to proceed from "discharge electrodes" chosen for their sharp edge surfaces (*e.g.*, thin wires and thin edged strips) to "receiving electrodes," composed of flat or curved surfaces.

The rapid ionisation at the discharge electrode can be regarded as due to the concentration of electric charge at the sharp edged surface. The air in contact with the electrode shares this charge and is immediately repelled, its place being taken by uncharged air, which, too, becomes charged and repelled, giving rise to convection currents between the electrodes. In this way there arises what has been termed an "electric wind" of considerable velocity from the discharge to the receiving electrodes. These currents of charged air are responsible for the communication of the electric charge from the discharge electrodes to the solid or liquid particles, resulting in their attraction to the receiving electrodes.

In practice, many pairs of electrodes are used in a single installation, the receiving electrodes being usually connected electrically to the structure of the gas chamber, and the whole electrically earthed. The discharge electrodes are electrically insulated. If the non-gaseous particles to be extracted are non-conductive, the insulators may be installed within the gas chambers themselves; but when acid mist

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* The patent rights are controlled by the International Precipitation Co., Los Angeles, California, U.S.A.; the representatives in Britain are Messrs. Huntington and Heberlein, Westminster.

is to be condensed, and its deposition upon the insulators would give rise to the breaking down of the insulation, it is necessary to place the insulators outside the gas chamber and to take special precautions to keep away the fumes.

Electrical precipitation is carried out by means of one of two types of treaters:—

(a) *Pipe treaters*, in which gases to be treated are caused to traverse metallic tubes at a velocity not exceeding 12 feet per second. Each of these tubes becomes a receiving electrode, the discharge electrode being formed by a thin wire, stretched along the central axis of each tube. A uni-directional potential of from 25,000 to 250,000 volts is applied, and the wire acts as the centre of discharge, the particles being precipitated on the walls of the tube, whence they are drained, if liquid, whilst, if solid, the current is shut off periodically, and the tubes vibrated to shake the dust down into bins.

(b) *Plate treaters*, as installed at Queen's Ferry, in which the gases pass between the rows of parallel vertical plates acting as receiving electrodes, and upon which the acid mist is deposited. The ionisation or discharge takes place at sharp-edged electrodes hanging midway between the plates.

STRUCTURAL DETAILS AND MODIFICATIONS.

General.—The Gaillard concentrators at Queen's Ferry consist of two houses of eight units each. Each house is connected to a separate lead flue, and both of these lead to a common flue, which runs along the end of the four treater chambers, and from which the gases pass through valves into the treaters themselves. From the chambers, after treatment, the gases pass into another common flue, from which two brick flues convey them to the stack. The plant will now be described in fuller detail.

Flues.—The lead flue conveying the gases from each house is rectangular in cross-section, and is constructed of 10-lb. lead strapped to timber supports. It is 2 feet 8 inches square at the end of the towers farthest from the treaters, increasing to 4 feet 2 inches deep by 2 feet 8 inches wide at the nearest end, being continued to the treaters with a cross-section 4 feet wide by 4 feet 2 inches deep. The fans from each tower deliver into this through an 18-inch diameter connection, set at an angle of 45° or 60° to the flue.
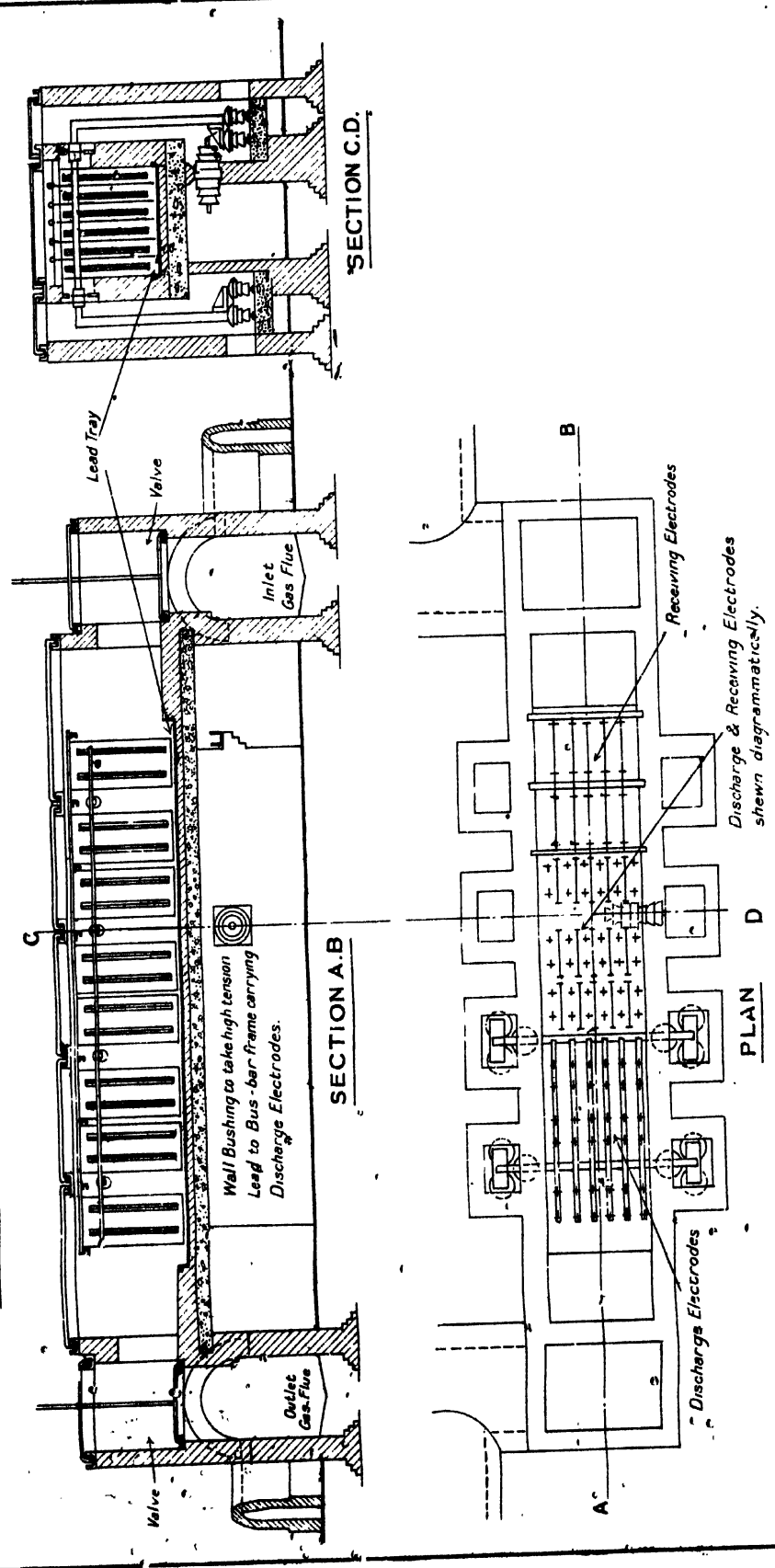
The flue from each Gaillard house drains from both directions towards the point of entry of the gases from the eighth tower, where the acid condensing in the flue itself is drawn off through a seal, and returned to the recuperator storage tanks *via* the fan drip launder.

The four treater chambers at present installed are built side by side, being connected at each end by an arched common brick flue 3 feet 7½ inches wide by 5 feet 2 inches high by 57 feet 9 inches long. These were originally constructed of brickwork, and were not lead lined. Frequent pointings being found necessary, however, lead lining has since been provided on the bottom of the inlet flue.

H. M. FACTORY QUEEN'S FERRY. COTTRELL PRECIPITATOR.

FIG 19.

Lead Tray

Valve

Inlet Gas Flue

SECTION C.D.

Wall Bushing to take high tension
Lead to Bus - bar frame carrying
Discharge Electrodes.

SECTION A.B

Outlet Gas Flue

Valve

Receiving Electrodes

B

Discharge & Receiving Electrodes
shewn diagrammatically.

Discharge Electrodes

PLAN

A

D

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The two lead flues from the towers conduct through lead-covered gas valves, luted with acid, into these common flues, at points between the first and second and third and fourth chambers respectively, as shown in Fig. 19.

Originally, the entry was effected through a short brick flue, leading to an arch in the common flue, 5 feet wide, by 3 feet high. As might be expected, this introduced a throttle in the path of the gases whenever more than six 50-ton towers were discharged into the flue. The resistance was demonstrated by a pressure up to 0·15 inch on the flue, which seriously increased the wear and tear on the lead work, giving rise to gas leaks, which had to be made good. Except, for slight sagging here and there, due to the insecurity of the timber supports, the lead flues have shown no other signs of wear and tear, beyond a tendency to leakage in the vicinity of the entrance to the common flue to the treaters.

In the case of one house, the difficulty has been overcome by raising the arch by three courses (13½ inches), thereby increasing its cross-section, and replacing the short brick flue by one of lead, in continuance of the main lead flue from the towers. This has been successful in eliminating the tendency to a positive pressure on the lead flue, and in effecting a material reduction in the wear and tear on the lead work.

It is possible, of course, that the original throttling was intentionally designed, in order to avoid undue pressure within the treaters, and so that the first signs of an overload might make its appearance as a pressure on the lead flue, the effects of which would not be so disastrous as a pressure inside the treaters at the port holes leading to the insulator chambers.

Treaters.—There are four independent treaters, built side by side, and connected, as mentioned above, by means of two common flues at each end. Each treater is 30 feet 1½ inches long by 7 feet 6 inches wide by 8 feet 6 inches high (inside dimensions), and is built on a 12-inch bed of reinforced concrete, raised about 4 feet 6 inches above the ground level, in order to enable the precipitated acid to run off by gravity into the storage tank. The concrete bed is covered with acid-proof brick, 6 inches thick, for a length of 23 feet 4½ inches in the centre, whilst for 3 feet 4½ inches at each end it is 15 inches thick, thus forming a well 9 inches deep, which is fitted with a lead tray. The concrete bed is supported by longitudinal brick walls, and is built so that its upper surface has a fall of 2 inches in its length towards the discharge opening for the precipitation acid at the gas inlet end.

The whole of the base of each treater is covered with an 8-lb. lead tray, 3 inches deep, the edges of which are flanged over 2 inches, and built into the brickwork which forms the walls of the chambers. The side walls are 13½ inches thick and the end walls stepped 13½ to 9 inches.

As will be more fully explained later, the capacity of the four chambers installed has not proved adequate for the requirements, and two additional chambers are to be installed, the four existing, treaters being rebuilt. Certain improvements will be introduced, the most important of which are as follows :—

(a) In the existing chambers, the concrete foundations only extended under each of the walls. These have proved insufficient, being partly responsible for the warping and cracking of the walls, with resultant leakage of acid. In the new chambers, the concrete bed will extend as a mat continuously under the whole structure, and should considerably increase its stability.

(b) The treater walls were not built solid, but consisted of an inner wall 4½ inches thick, built with acid-proof cement, and an outer wall 9 inches thick, built with ordinary cement. The courses in the outer wall were level, whilst those in the inner wall were parallel to the sloping base of the chamber. No bonder courses were introduced, so that the strength of the wall was not what it might have been. The walls have warped very badly and acid has leaked through, and run down between the inner and outer walls, causing very serious corrosion on the concrete bed.

(c) The treaters already installed at the Cottrell plant in connection with the Gilchrist concentration plant are lead-lined throughout, which should overcome the trouble occasioned by the leakage of acid from the chambers.

The weakness of the walls in the existing treaters has been overcome to some extent by the provision of steel stays. In the case of the Gilchrist treaters and those proposed for erection in connection with the Gaillards, the brickwork is being strengthened initially by the provision of adequate staying.

Fuller discussion of the design of the new treaters will be given in succeeding sections. A diagrammatic sketch is shown in Fig. 20, which illustrates the essential features of the modifications in construction.

Insulating Chambers.—In the existing type of treater, four brickwork chambers are erected at each side of each treater in which to instal the insulators carrying the supporting framework for the discharge electrodes. These extend from the ground level to the top of the main chamber brickwork, having a total depth of 13 feet 3 inches, the lower, 3 feet 3 inches, having a cross-section of 2 feet 10½ inches by 2 feet 9 inches, whilst the remainder has a cross-section of 1 foot 9 inches by 2 feet. These chambers are spaced systematically about the centre line at 5 feet 7½ inch centres, and connection is made between them and the main precipitating chamber by rectangular openings, 20 inches high by 18 inches wide, the tops of which are 10 inches below the top of the chamber brickwork, these openings
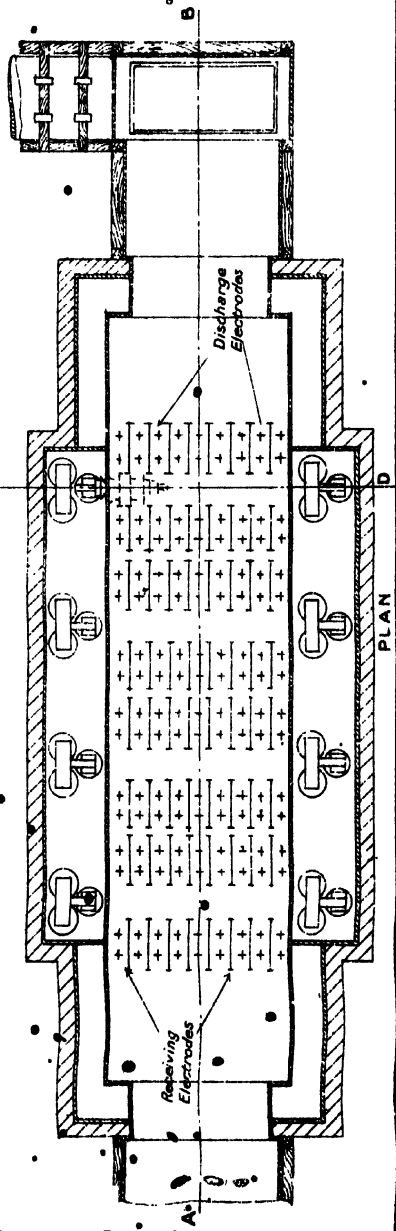
H.M. FACTORY QUEEN'S FERRY.

COTTRELL PRECIPITATOR.

DETAILS OF PROPOSED NEW TREATERS.

6 lb Lead

Valve

Inlet Flue

C.I. Plate

8 lb Lead

to Stack
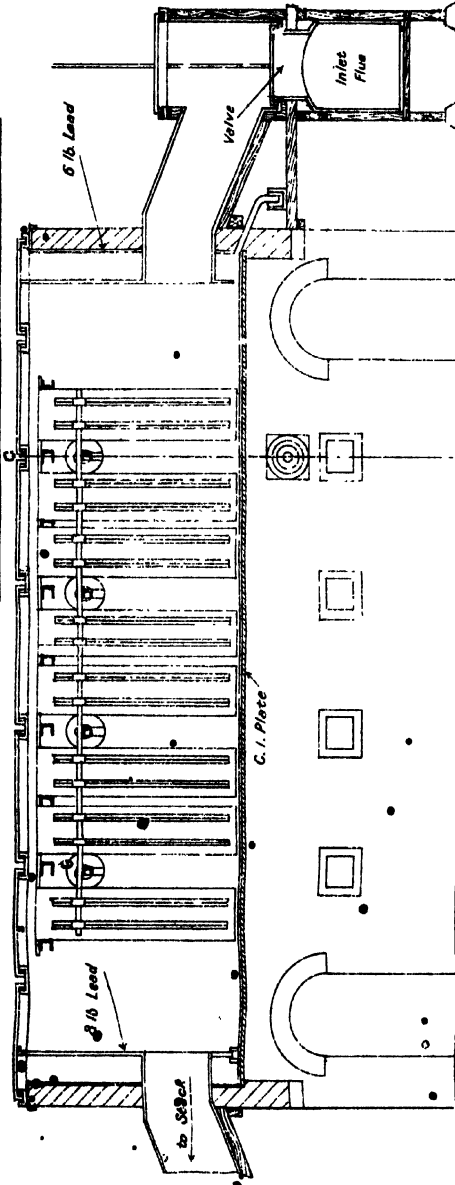
SECTION A.B

SECTION C.D.

The Inner Lead Electrode Chamber is supported on a framework of Channel Iron, not shown in drawing.

FIG. 20

Discharge Electrodes

Receiving Electrodes

PLAN

H. & G. GRAHAM LTD. LITH? LONDON.S.E.

affording passage-way for the cross-members of the discharging electrode frames. In order to restrict the quantity of air drawn into the chamber by the fan inducing the draught, the openings were originally partially closed by means of lead-covered wooden blocks which left an oval hole round the bar passing through into the treater, with a 3-inch free space between it and any part of the circumference of the hole. Modifications of this will be indicated later.

In the side of each insulating chamber at the bottom, an opening 18 inches square, fitted with a cast-iron framed door, gives access to the insulators carrying the discharge electrode supports. An adjustable slot in the door provides for the regulation of the admittance of the air.

The high tension lead conducting to the discharge electrodes is taken into one compartment of each unit, which is fitted with a porcelain insulator brush.

Stack and Induced Draught.—The common brick flue receiving the gases as they leave the treaters has two outlets, 5 feet wide by 5 feet high, which lead to the stack through two arched flues, 3 feet wide by 5 feet high.

The stack is built on a piled concrete foundation and is 9 feet 9 inches diameter by 100 feet high. It consists of two parts, an outer casing and an inner lining, forming the throat and chimney on the Prat system, the latter part being carried on corbels inside, the outer casing.

The outer casing is 9 feet 9 inches inside diamer, parallel throughout, except for corbling. The inner lining commences 21 feet above the foundation block, and starts at 9 feet 6 inches diameter, gradually reducing to 5 feet $1\frac{1}{2}$ inches diameter in 11 feet, and remaining at this for 12 feet 9 inches, afterwards increasing to 9 feet diameter at the top of the stack. The whole of the inner casing is built of acid-proof brick and is not bonded to the outer casing. It is thus readily removable at will.

At the centre of the stack is built an axial upcast, the top of which is 28 feet 3 inches above the foundation level. This serves for the passage of the air from the fan which induces the draught in the chimney, after the manner of an injector. The upcast is 4 feet in diameter (walls 9 inches thick) to a height of 21 feet above the foundations, and is gradually tapered, in $4\frac{1}{2}$-inch brickwork, to a diameter of 2 feet $6\frac{1}{4}$ inches at the top.

The base of the upcast is connected to an opening, 4 feet in diameter, in the outer lining of the shaft, and thence to the fan. This is a 45-inch inlet Sirocco fan, fitted with a pulley on one side only. It is driven by an 80-h.p. motor, originally at a speed of 580 r.p.m.

Modifications in Draught in extended Plant.—The existing fan is hardly sufficient, even when speeded up, to cope with the gases from four chambers working to full capacity. The six chambers of the complete plant will be served by two similar stacks, with two fans, of the

same type as the existing fan, both driven at a higher speed by 150-h.p. motors.   It seems questionable, however, whether the fans will be able to stand the extra strain.   A third bearing on the outer side of the pulley will be necessary, and in all probability the impeller blades will need strengthening.

The induced draught is also to be produced in a somewhat different manner, as shown in Fig. 21.   The axial upcast will no longer obstruct the passage of the gases up the stack, and the inducing of the draught will take place in the flue leading to the stack.   Instead of using a cylindrical stream of air from the fan as at present, the cross-section of the blower will be on the pattern of the pottery injector fans in use on the retorts and denitrators, i.e., it will form a hollow ring, the gases from the chambers passing both inside and outside of the air from the fan.   This should certainly prove more effective.

ELECTRICAL PLANT.

General.—For the production of an electric field suitable for cleaning gases, it is essential to have :—

(a) A uni-directional polarity for the potential difference between mating electrodes.

In order to precipitate mist from stationary air, e.g., fog, an alternating electric field can be used.   This results in charging different particles of mist positively and negatively, as the polarity of the discharge electrodes alternates.   Oppositely charged particles attract each other and coalesce, with the result that, ultimately, the particles are large enough in size to fall under the influence of gravity. This method, however, is not applicable to moving streams of gas.

(b) A sufficiently great difference of potential.

The method adopted is, first of all, to secure the necessary difference of potential by means of a suitable transformer, and then to secure uni-directional polarity by the utilisation of a rectifier.

The electrical plant requisite for this purpose is installed in the rectifier house, and at present consists of five units, four of which are connected up, one to each separate treater, and a spare unit capable of being connected to any one of the treating chambers.

A three-phase feeder from the 440-volt supply is brought into the rectifier house and terminates on a distribution board, from which the five switch boards controlling the separate rectifier units are supplied. All three phases are connected to the synchronous motors driving the rectifiers, whilst connections to the transformers are tapped off two phases, giving a resultant single phase.

Discharging Electrodes.—The general arrangement of the electrodes is shown in Fig. 22, which also illustrates the general lay-out of the whole plant.   The discharge electrodes are those connected to the high tension lead from the rectifiers.   They consist of bars of antimonial lead, 7 feet 1⅝ inches long, and of cruciform cross-section, the four

FIG. 21.

H. M. FACTORY QUEEN'S FERRY.

COTTRELL PRECIPITATOR.

SHEWING METHODS OF SECURING DRAUGHT.

SECTIONAL ELEVATION
OF PRESENT METHOD.

Stack
100 ft high

Air from Fan

Flue from Precipitator

Stack
100 ft high

Fume

Air

Air

Air from Fan
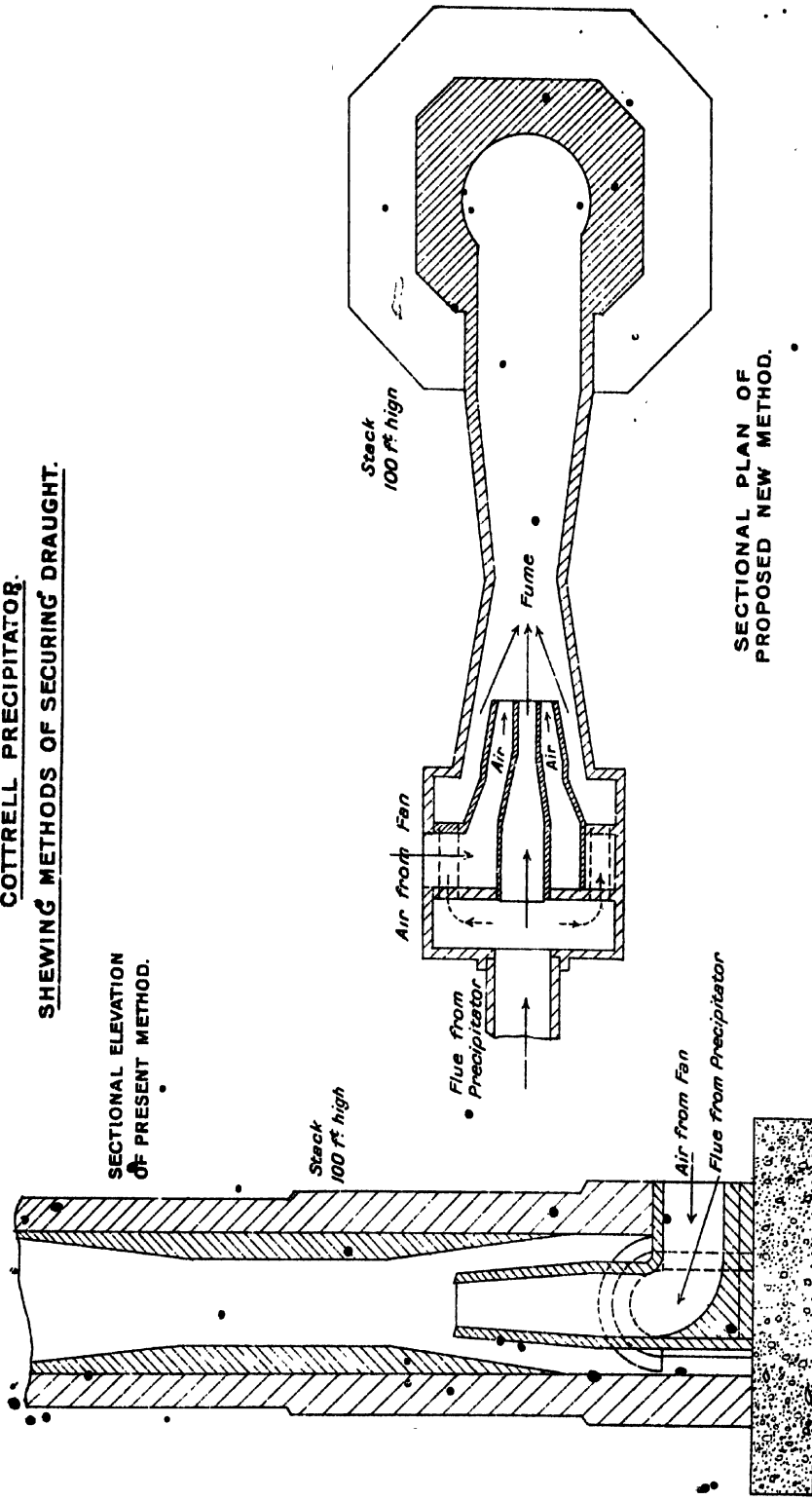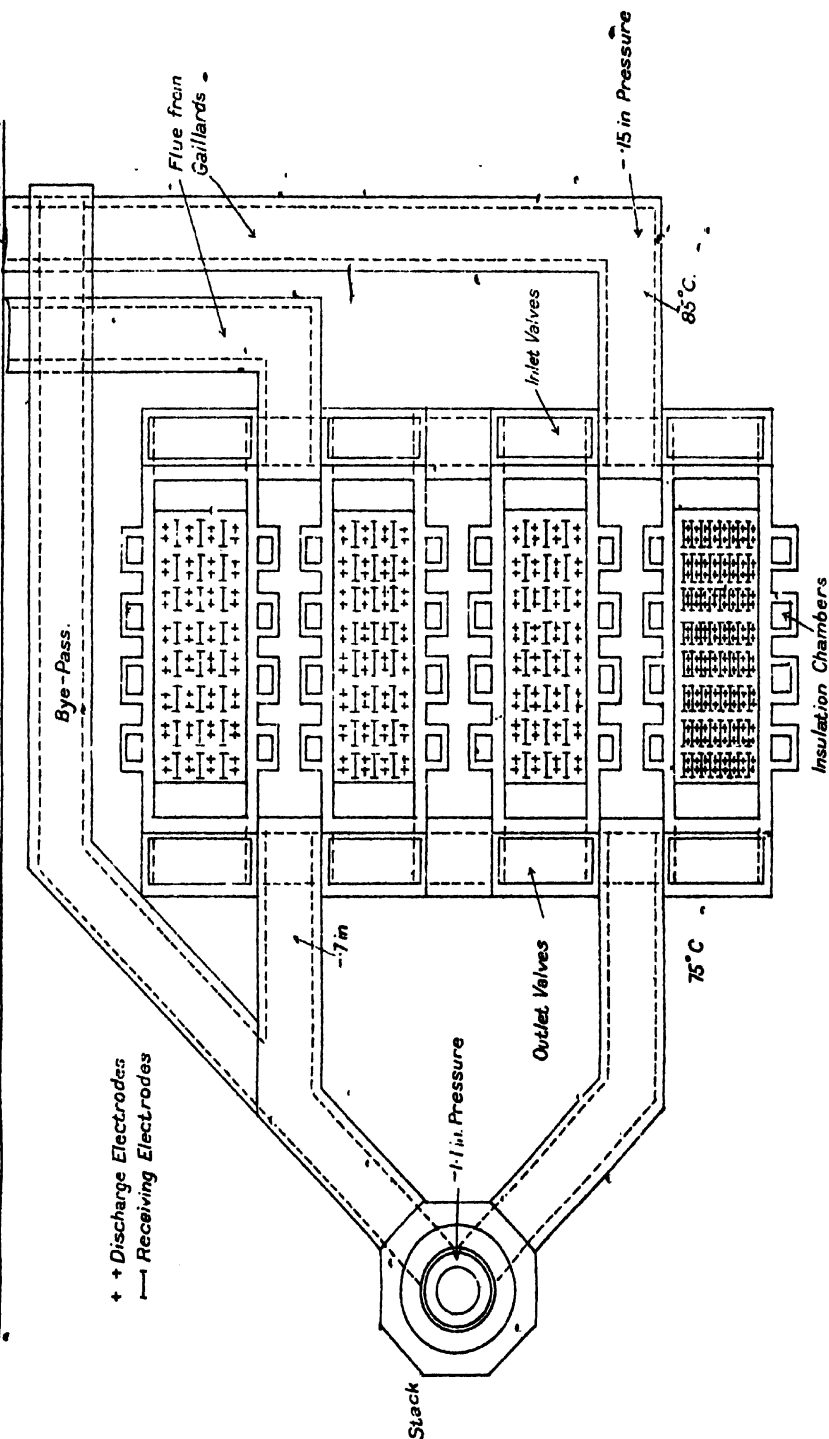
Flue from
Precipitator

SECTIONAL PLAN OF
PROPOSED NEW METHOD.

FIG. 22.

H. M. FACTORY. QUEENS FERRY.

GENERAL ARRANGEMENT OF PRECIPITATOR CHAMBERS AT GAILLARD TOWERS.

ELECTRODES IN LOWER CHAMBER TO SCALE OTHERS DIAGRAMMATICALLY. SCALE, 1/16 IN—1 FT.

+ + Discharge Electrodes

— Receiving Electrodes

Flue from Gaillards

·15 in Pressure

85°C.

Inlet Valves

Insulation Chambers

Bye-Pass.

·7 in

75°C.

Outlet Valves

·1·1 in. Pressure

Stack

wings being each 1 inch long by $\frac{1}{8}$ inch to $\frac{3}{16}$ inch thick. These hang between receiving electrodes, and the two opposite edges facing the receiving electrodes are sharpened as finely as possible to facilitate convectional discharge. The initial sharpening has been sufficient, up to the present, the corrosion suffered having proved negligible.

Two discharge electrodes, 12 inches apart and equi-distant from the corresponding vertical edges of the receiving electrodes, are hung midway between each pair of adjacent receiving electrodes. The discharge electrodes are burned, in sets of eight, to lead-covered steel bars, so that the lower end is 6 feet 3 inches below the bar. There are 18 bars for each chamber, so that each treater has 144 discharge electrodes. The bars are supported on lead-covered steel bars, mounted edgwise, which pass under the receiving electrode supports and pass through the holes in the upper part of the chamber walls into the insulating shafts, where they are secured at each end to a vertical channel stancheon, mounted upon three supporting porcelain insulators.

The total number of insulator supports in each chamber is thus 8 by 3, i.e., 24. This number could be reduced, and the whole supporting system simplified in the new type of chamber by installing the insulator at the top of the insulator chambers. With a single insulating chamber upon either side of the treater, as there will be in the new type, three sets of two insulators upon each side would suffice to support a bus bar, upon which the lead-covered cross-channels could rest. This would halve the total installation of insulators per treater and also reduce the risk of acid dripping down and disturbing the insulation. The air rising past the lead walls of the chamber lining would be fairly warm before reaching the insulators, and this would consequently considerably diminish the chance of fume or moisture being deposited.

Receiving Electrodes.—These consist of sheets of soft 8-lb. lead, 2 feet wide by 8 feet 5 inches long, the upper ends of which are burned round lead-covered mild steel bars $1\frac{1}{4}$ inches in diameter. The plates are carefully flattened and stiffened by angles of 8-lb. lead, 1 inch by $1\frac{1}{2}$ inches, which are burned to the vertical edges.

At the top of the chambers, nine 5-inch by $5\frac{1}{2}$-inch channels lie across them at right angles to the walls, and supported in them at distances $33\frac{3}{4}$ inches apart. Each channel is completely covered with 8-lb. lead. The channels serve to support the receiving electrodes which hang vertically from them, so that the surfaces of the plates are parallel to the chamber walls. Plates are hung 10 inches apart (centre to centre) and it is not necessary to hang any plate at the walls, since the wall surface is itself conductive, and will serve as a receiving electrode when wet with acid.

Eight rows of receiving electrodes (64 in all) are hung across the chambers in this manner, being prevented from swinging by means of lugs burned on to the lead pan.

Primary Circuit of High Tension Transformer.—Originally, the primary circuit of the high tension transformer included :—

(a) *A breaker*, set to trip as soon as the current in the primary circuit reached 25 amperes. This is a safeguard in emergency, in the event of sudden abnormal short-circuiting on the high tension circuit or the rectifier. Usually, however, leakage of this kind is observed before the breaker comes into operation.

(b) *An ampère-meter* which indicates the current in the primary circuit. This usually varies between 15 and 16 amperes.

(c) *An auto-transformer*, by means of which the voltage fed to the high-tension transformer is regulated. Originally the full pressure of the 440-volt circuit was put on the auto-transformer, from which intermediate pressures varying between 190 and 440 volts could be tapped by means of a dial switch with 18 tappings. This permitted the secondary voltage on the H.T. transformer to be regulated between 35,000 and 82,000 volts.

The ratio between the secondary and primary windings of the H.T. transformer is naturally invariable, being of the order of 186 : 1.

(d) *A variable grid resistance of* 6 ohms, which served still further to adjust the H.T. voltage by varying the voltage on the primary windings of the H.T. transformer.

Modifications of Auto-transformer and Grid Resistance.—The arrangements of auto-transformer and grid resistance outlined above did not prove altogether satisfactory. The main resistance in the primary circuit being the inductive resistance of the auto-transformer, the current proved unsteady and oscillated considerably. As a result of this, it was not possible to work the chambers at the desirable voltage, and this naturally reacted on the efficiency of precipitation.

In consequence, a successful attempt was made to substitute additional ohmic resistance for a certain proportion of the inductive resistance. To accomplish this, the method adopted aimed at securing a higher voltage from the auto-transformer, and then reducing to workable limits by the introduction of an additional grid resistance. The present arrangement of the auto-transformer consists in connecting the 440-volt supply to a section only of the windings. The primary circuit of the H.T. transformer can tap, when necessary, the full windings of the auto-transformer, which gives, on the present working, up to 600 volts on open circuit.

The original 6-ohm variable grid resistance has been retained in the primary circuit, and an additional 6-ohm invariable resistance introduced.

By this partial substitution of ohmic for inductive resistance, steadier voltage has been obtained at the H.T. transformer, and it has been possible to maintain the H.T. current at higher average voltages than was originally the case.

The changes effected are shown diagrammatically in Fig. 23.

FIG 23.
H.M. FACTORY QUEEN'S FERRY.
COTTRELL PRECIPITATOR.
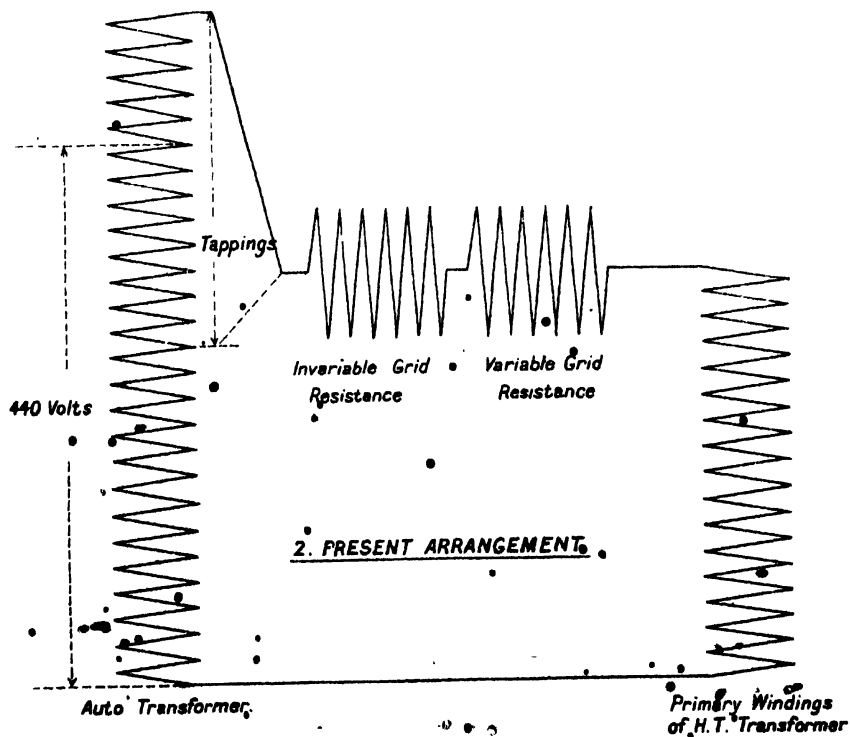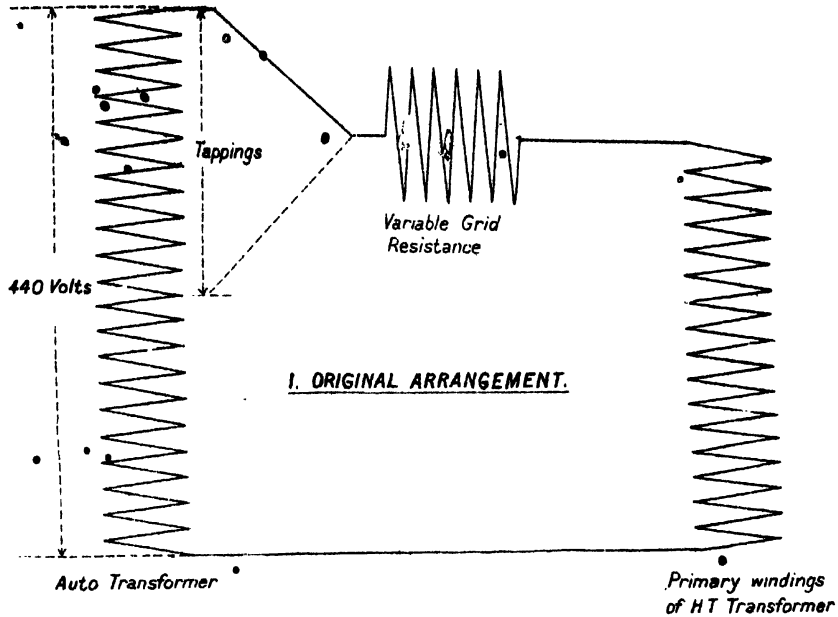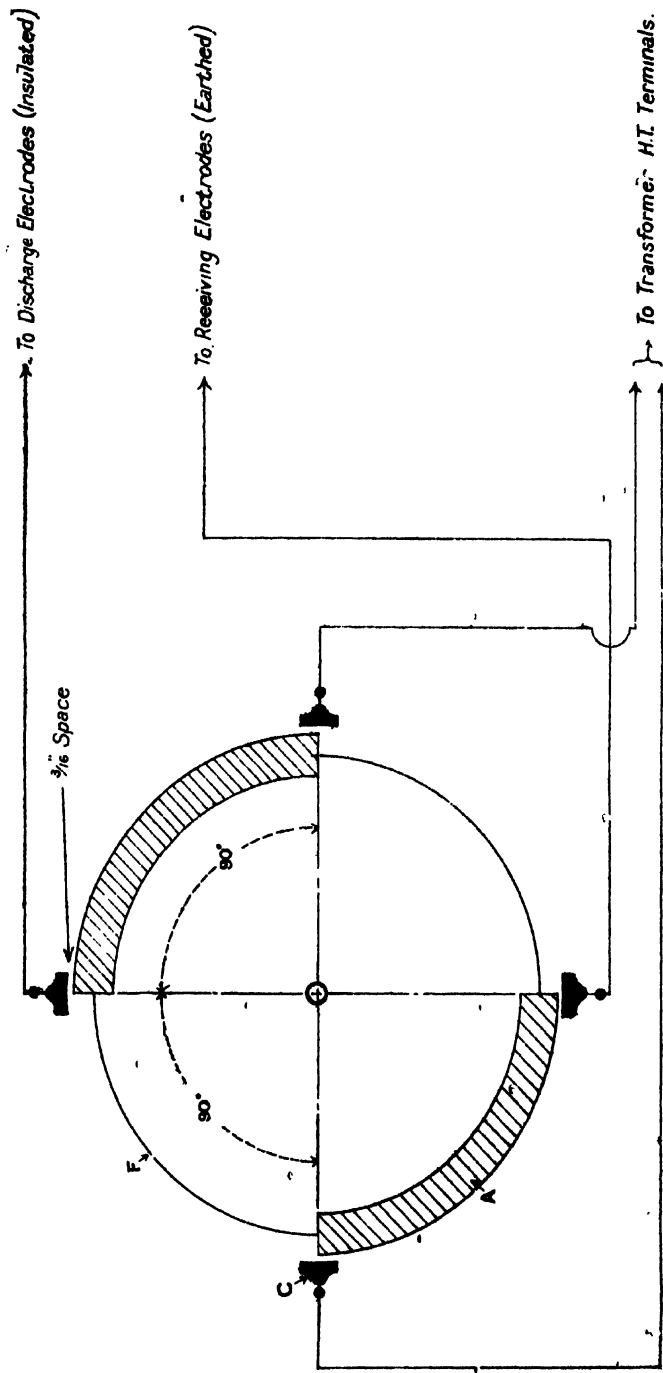#### DIAGRAM OF PRIMARY CIRCUIT OF H.T. TRANSFORMER.

Tappings

Variable Grid
Resistance

440 Volts

I. ORIGINAL ARRANGEMENT.

Auto Transformer

Primary windings
of H T Transformer

Tappings

Invariable Grid
Resistance

Variable Grid
Resistance

440 Volts

2. PRESENT ARRANGEMENT.

Auto Transformer.

Primary Windings
of H.T. Transformer

FIG 24.

DIAGRAM OF RECTIFIER.

To Discharge Electrodes (Insulated)

To Receiving Electrodes (Earthed)

To Transformer. H.I. Terminals.

³⁄₁₆″ Space

90°

90°

F

A

C

Polarity of Discharge Electrodes.—It is a recognised principle of electrical precipitation that the negative pole of the rectifier should, by preference, be connected to the discharge electrodes, the positive pole, together with the receiving electrodes, being connected to earth. To render this possible, a reversing switch is provided on the switchboard. When the polarity of the discharge electrode is positive, considerable sparking is manifested at the rectifier and there is an increased liability to disruptive discharge within the chambers. Much smaller voltages can be sustained when the positive pole is insulated than when the polarity of the discharge electrodes is negative. The latter is certainly most favourable to silent convectional discharge.

Rectifiers.—The secondary windings of the H.T. transformer are connected to two of the terminals of the current rectifier, whilst the other two terminals are connected, one to the feeder to the precipitator chamber and the other to earth.

The terminal of each rectifier, from which the current is carried to the precipitating electrodes, is connected to high tension insulators carried upon channel supports, the top of each insulator being fitted with a metal plate, to which is hinged a $\frac{1}{4}$-inch diameter steel rod 2 feet 5 inches long. Under normal working conditions, the outer extremity of this bar rests upon a metal plate attached to the top of a similar insulator erected adjacent thereto on the same channel support, which, in turn, is connected to the main feeder, supported by insulators suspended from the roof trusses and leading the current to the discharge electrodes. By means of an insulated pole, the hinged rod may be lifted and turned through 180°, at which point it comes against a stop attached to the channels carrying the main insulators, which are bonded to earth, thus disconnecting the rectifier to which it is to be connected, from the feeder to the precipitating chamber.

Each of the four units is capable of being directly connected to one of the precipitating chambers, the conductor consisting of a $\frac{3}{4}$-inch steam pipe carried on insulators attached to the roof ties, and passing through the wall of the building through long petticoated porcelain bushings. Each of the four conductors runs nearly the full length of the rectifier house, so that any one can be readily connected to the main conductor from the spare unit, which is a transverse bar capable of being linked up to any feeder.

The rectifier, the essential features of which are shown in Fig. 24, consists of a disc of insulating material, 24 inches in diameter, which is directly connected to the shaft of the synchronous motor driving it. Upon the periphery of the disc are fastened two metal segments, the curved edges of which have a radial centre common with that of the disc. The segments extend 90° along the periphery, and are separated from each other by 90° of the disc.

In the plane of the segments the four stationary contacts, or shoes, are held 90° apart, and are so adjusted that as the disc rotates the outer edges of the segments pass consecutively by them with a uniform clearance distance of $\frac{3}{16}$ inch.

PLANT AND PROCESS DIFFICULTIES.

Effect of an Overload on Insulator Chambers.—Various troubles have arisen with regard to the insulator chambers, the chief of these being due to serious overloading of the plant. In the event of an overload on the chambers, due to the Gaillard fans pushing the gases into the treaters at a faster rate than the fan inducing the draught can cope with, gases are forced down the insulator shafts instead of air being drawn up. The consequent deposition of acid mist upon the insulators has resulted in short-circuiting and disruptive discharges. This necessitates shutting off the current on the particular unit affected for the cleaning of the insulators.

It is fairly obvious, therefore, that it is impossible to work the plant with any success, unless the condition of overload is avoided. This was not always possible originally, as all the gases from the Gaillards had to pass through the chambers, and no provision was made for the event of the precipitators being at any time incapable of dealing with the total volume of gas issuing from the towers. This condition arose whenever—

(a) More than 12 towers were in operation at any one time. During one period this was frequent, as the TNT acids cycle was working up to its maximum capacity.

(b) One or more chambers were thrown out of action for repair.

Methods of overcoming Overload.—The only solutions to the difficulty were the following :—

(a) The provision of a bye-pass, for use whenever the chambers proved for any reason incapable of handling the volume of gases produced. This is obviously only a temporary expedient, until such time as more satisfactory measures can be brought into operation.

A lead flue, 6 feet high by 5 feet wide, similar to those connecting the fan exits to the Cottrell chambers, was installed to connect the lead flues from the houses direct to the main stack. Dampers provided for the regulation of the amount of gas bye-passed from each flue in this way.

This measure has done away with most of the insulator trouble due to fume, but the final remedy must obviously be to increase the capacity of the Cottrell plant itself. The two methods next-mentioned would bring this about.

(b) An increase in the number of chambers. As mentioned previously, this is already in hand.*

* This was written in May 1918, and the work referred to was completed shortly after that date.

(c) An increase in the draught induced by the Cottrell fan. More will be said concerning this in connection with the discussion of the fan itself. It is sufficient here to point out that the increase in the volume of gases passing through each chamber which could be brought about in this way is not necessarily desirable. The greater the velocity of the gases, the less the ionisation per unit volume, and, within limits, the lower the efficiency of the plant.

The total induced draught must, of course, be increased, but this should be utilised on an increased number of chambers, as it is questionable whether any single chamber should be called upon to treat a heavier load than it bears at present.

Other Insulator Chamber Troubles.—The other main troubles in regard to the insulating chambers have been as follows :—

(a) The 3-inch clearance distance between the bus-bar passing through the opening to the main chamber and the circumference of the oval aperture has proved too small.

The problem of *clearance distance* is exceedingly important. The whole structure of the chambers constitutes part of the receiving electrode system, so that it is essential to prevent disruptive discharge from the discharge electrodes to any part of the chamber. The distance at which disruptive discharge will take place depends upon the character of the surfaces as well as upon the difference in potential. For a given difference of potential, the distance permissible without the danger of a disruptive discharge is least for two flat surfaces of opposite polarity, and greatest for two edged surfaces. Only flat or round surfaces can be brought to close distances; any edges or corners increase the risk of disruptive discharge.

The 3-inch free space mentioned proved insufficient, which has necessitated removing the blocks from the opening and increasing this to about 15 in. × 10 in.

It is a sound practice to assume that the smallest distances between surfaces of opposite charge must be those between the actual electrodes, which for these precipitators are equal to about 4 inches. Other distances should be 50 per cent. in excess of this. The apertures mentioned could probably be reduced to, say, 4½ inches clearance by rounding the surfaces of the aperture by introducing around it lead-work of oval circumference, bent to a radius of 3 or 4 inches.

(b) The cold air rising up the insulating shaft and passing into the insulating chamber has given rise to the deposition of crystals of nitro-body upon the electrodes in the vicinity. This could be overcome by warming the air before admittance, and would be secured by the new form of treater mentioned below.

(c) Minimum clearance distance between the edges of the supporting insulators at the base of each shaft is only about 2 inches. This is sufficient, provided insulation is adequate. Whenever the surface of the insulator becomes conductive, however, due to a coating of acid, disruptive discharge occurs across the short distance to the wall. The remedy is to increase the clearance distance, which has been done by hollowing out the wall to give a clearance distance of about 4 inches.

(d) In addition to the breaking down of the supporting insulators due to acid fume, acid persistently leaks through the walls of the chamber and drops on to the insulators. This trouble will probably be overcome in the new treaters. In these, the separate insulating chambers are cut out altogether, the insulators being installed between the walls of the treater, which are built of 10-lb. lead, supported by a steel framework and the rectangular outer brick walls of the outer structure. There will thus be two main insulation chambers, one on each side of the treater. Fig. 20 shows the arrangement quite clearly.

A weak spot will probably arise, due to the absence of lutes at the top of the lead inner chamber. In the existing chambers, the whole of the precipitator chamber and the small insulating chambers are closed, by covers sitting in water-sealed lutes. The cover for the main chamber is in five sections, and those for the insulating chambers are separate. These lutes are 3 inches deep. In the new chambers, however, lutes are only provided on the outer walls, and the two covers will extend the full width of the treater. There will thus be serious risk of the leakage of fume over the top of the lead-work lining the treater chamber into the insulating chambers, especially as the covers do not sit absolutely tight.

(e) On account of the inadequacy of the concrete foundations, the levels of the lutes have been seriously affected, so that the suction on the insulation shafts due to the induced draught of the Cottrell fan is sufficient in the case of the lutes of lowest level to suck the water (usually slightly acid) into the shaft. This falls on the insulation and is a further source of trouble.

It would probably be an improvement in future installations, if the insides of the lutes to the insulator chambers could be raised ½ inch higher than the outsides. This should effectually overcome the risk of water being drawn into the insulator chamber by the suction of the fan.

Spacing of Electrodes.—In order to secure the maximum efficiency of the precipitator, it is essential to preserve even spacing between the electrodes. It is a sound practice in any electrical precipitation plant to

work to the highest difference of potential possible, consistent with the absence of disruptive discharge. Any inequality in the spacing of the electrodes will increase the liability to such breaking-down of the dielectric at the reduced dielectric distances, so that failure to pay due regard to the spacing of the electrodes will react immediately upon the efficiency of the plant.

There is little difficulty in altering the positions of the receiving electrodes. The bars supporting these may be moved at will along the supporting channels. It is not so simple to adjust the position of the discharge electrodes. Originally the location of these was fixed, inasmuch as the lead-covered steel bars from which they hung were supported in notches in the lead-covered steel channels. By having these notches cut in a support of regulus metal, instead of steel, the difficulty can, however, readily be overcome.

Rectifier Discs.—The discs used are made of bakelite, and have proved very satisfactory. The only trouble has arisen when the acid fumes have entered the rectifier house and settled on the discs. This, if allowed to accumulate, renders the surface conductive, and discharge occurs along the edge of the disc and across the surface between the metal segments. This not only disturbs the electric field, but also chars the bakelite, and furrows the surface, leaving a coating of carbon behind. It is necessary to scrape this off before starting the rectifier again, as the carbon is an electrical conductor. When the edges have become too much affected for further scraping, the circumference of the insulating portions between the metal discs has been reduced on both sides by ½ inch or so.

The rectifier discs are usually dried and wiped over with methylated spirit, whenever there are any signs of arcing between the metal plates.

Insulators.—There has been considerable trouble due to cracking of insulators. This was at first attributed solely to the results of disruptive discharges arising from the deposit of acid fumes upon the porcelain. Investigations has shown, however, that :—

(a) The insulators installed were not large enough for the duty required of them, being only 66,000-volt insulators, whereas 100,000-volt insulators are desirable. These would still be of the mushroom type in the rectifier house and the insulating chamber of the precipitators. Chain insulation would, however, probably be useful in connection with the lines running between the rectifiers and the chambers.

(b) The cement used in building up the insulators installed was not of acid-resisting type. In consequence it was attacked by acid and the swelling that resulted was, in many cases, responsible for the frequent cracking.

Earthing.—As stated previously, the receiving electrode system is electrically earthed. This was originally accomplished by means of ¾-inch steam pipes, leading underground to a lead earth-plate. The

ground around the Gaillard towers is, however, fairly saturated with dilute sulphuric acid, with the result that the connecting piping has been corroded in places, necessitating the installation of new overhead connections to earth. For this reason, future earthings will be brought about by the overhead system. Connection will be made by overhead cables to the steel framework supporting the treaters.

### FURTHER POSSIBLE MODIFICATIONS IN CONSTRUCTION.

On the basis of experience at Queen's Ferry, the construction of the treater chambers in the manner illustrated in Fig. 25, has been suggested. The main features of the suggestion are as follows :—

(a) There is no need for chambers to be built absolutely detached as they are at present. It is, therefore, suggested that they be built with only a single wall between adjacent chambers. It is an obvious saving in the cost of erection, apart from the economy of space, which might also be a consideration in some cases.

(b) The walls and bases of the precipitator chambers to be constructed of sheet lead, supported by a steel framework, as suggested in the new type of treater at present under erection, but lutes to be constructed as in the original treaters, along the tops of the precipitator chamber walls, as well as on the top of the party walls between adjacent precipitators. This would obviate the necessity of constructing unwieldly covers to cover the full width of the chambers and would permit the use of separate covers for the insulator chambers. A further gain would be that the luting at the top of the lead lining would be a protection against the leakage of fume into the insulating chambers, which is an important point.

(c) The supports to the discharge electrodes to be, as suggested previously, at the top of the insulating chambers instead of at the bottom. The results of this modification would be :—

(1) Increased strength in the arrangement. The present plan of supporting the heavy vertical stanchions on a base of three insulators undoubtedly gives a weaker mechanical structure.

(2) Reduction in the number of insulators required to 12 per chamber, in place of twice that number, which are at present in use.

(3) Reduction in the size of the insulator chambers, which need no longer extend to the base of the structure. There would be no advantage in extending the base of the insulator chambers below the base of the treater chambers.

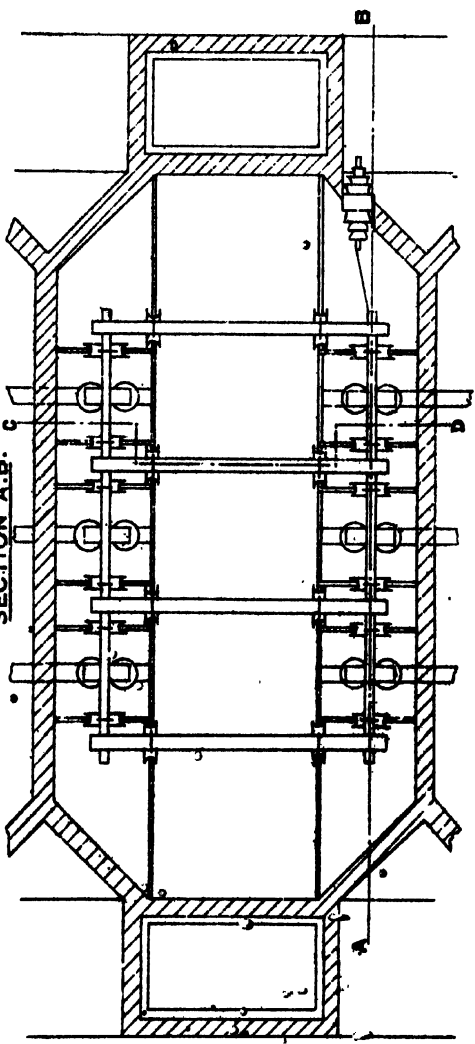(4) Increased simplicity in the connection of the H.T. feeder to the discharge electrode system.

H.M.FACTORY QUEEN'S FERRY COTTRELL PRECIPITATOR.

SHEWING SUGGESTED MODIFICATION OF TREATER.

SCALE ⅛ IN.=1FT.
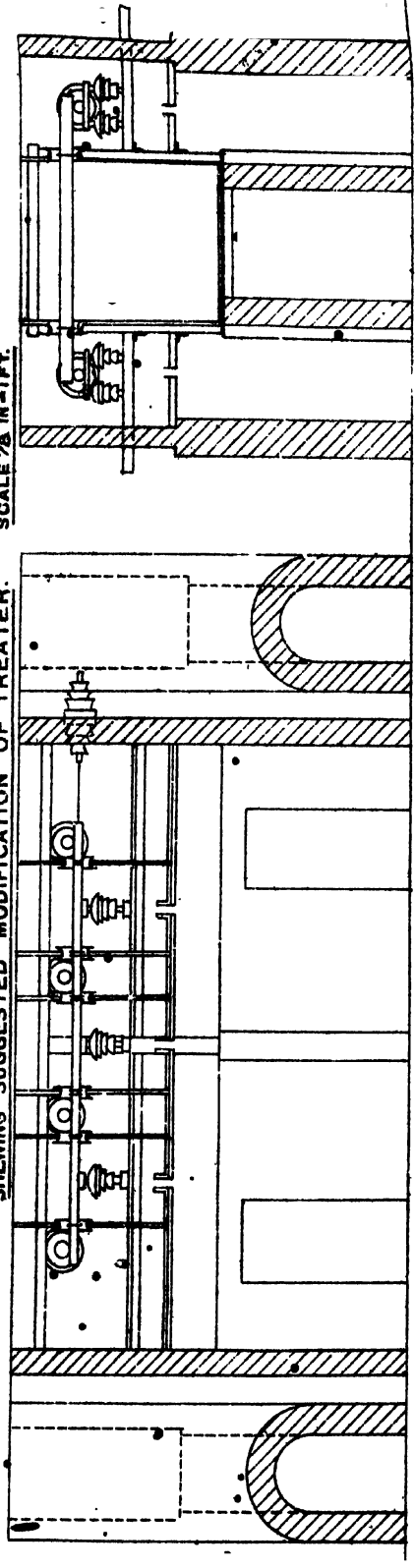
SECTION C.D.

Electrodes & Arrangement of
Lutes not shown.

FIG. 25

SECTION A.B.

(d) The insulators supporting the bus-bar carrying the discharge electrodes supports, to be contained in three special lead-lined chambers on either side of the precipitator chambers. These do not connect directly with the precipitators. Air passes through these insulator chambers from the base, being partly warmed as it passes by the lead lining of the chamber, and then through special ports into the adjacent chambers, which open through the ports in the walls of the precipitator chambers into the precipitator themselves.

This would afford special protection to the insulators against the deposit of acid-fume, and this is an essential point in the design of precipitator plants erected for the precipitation of acid mist.

(e) All port holes are constructed as suggested previously. The circumferences are formed by strips of 3-inch radius lead, bent so as to present a convex curved surface to the discharge electrode supports. The aim of this is, of course, to present a type of surface least likely to give rise to disruptive discharge between itself and the charged conductors. Convectional discharge is encouraged by burning on edged strips of lead to the bus-bars at the central positions of the ports. This should afford additional security to the insulators, in that it increases the likelihood of any mist passing through the ports being ionised and deposited before the insulators are reached.

CAPACITY AND EFFICIENCY OF THE PLANT.

Capacity of Plant. — This can be regarded from two points of view :—

(1) *The volume of gases that can be passed through the treaters, while still preserving a suction on the insulating chambers.* — In the initial stages of operating an electrical precipitator, when insulation troubles are critical, this is apt to be the main criterion of the capacity of the plant. The existence of a pressure on the insulating chambers, however, only means that the Cottrell fan is not properly proportioned to its load.

(2) *The volume of gases that can be effectively scrubbed of their mist-content.* — This brings into account the question of efficiency of precipitation, which is the only satisfactory standard to apply.

With a 75 per cent. efficiency, the maximum steady load that can be borne by the four precipitating chambers seems to be in the neighbourhood of that required in connection with the concentration of 400 tons H_2SO_4 per day from 67 per cent. to 93 per cent. Thus, each chamber can deal with the gases from 100 tons H_2SO_4 per day.

100 tons H_2SO_4 require (on present working) 13 tons of coal = 29,120 lb.

O 11455

Assuming that the available carbon content of the coal is 74·0 per cent.,

Then, 29,120 × 0·74 = 21,560 lb. of C.

$$\frac{21,560 \times 44}{12} = 79,000 \text{ lb. of } CO_2.$$

$$\frac{79,000 \times 357·5}{44} = 648,100 \text{ cub. ft. of } CO_2 \text{ per 24 hours.}$$

Analysis of gas entering treater showed 6·2 per cent. CO_2 :—
This gives per treater,

$$\frac{641,800 \times 100}{6·2 \times 1,440} = 7,180 \text{ cub. ft. of gases per minute at } 0° \text{ C.}$$

$$= 9,420 \quad „ \quad „ \quad „ \quad „ \ 85° \text{ C.}$$

Corresponding Gas Velocities.—Cross-section of each treater, neglecting the electrode space, is 63·75 sq. ft.

∴ Velocity through treater = 2·5 ft. per sec., or allowing for electrode space, = 2·7 ft. per sec.

This figure takes no account of the air entering the treater through the insulating chamber. An analyses of the gases leaving the treater showed 5 per cent. of CO_2. This would be secured by the addition per minute of—

$$7,180 \times \frac{1·2}{5·0} = 1,720 \text{ cub. ft. of air at } 0° \text{ C.}$$

Total volume (7,180 + 1,720) -   -   - 8,900 cub. ft. at 0° C.

Assuming air at   -   -   -   - 15° C.

Average temperature of air and gases - 71° C.

∴ Volume of gases at 71° C.   -   - 11,200 cub. ft. per min.

On this basis the average velocity through the treater, allowing for electrode space, will be 3·1 ft. per sec.

This seems fairly representative of what can be regarded as a safe load for the existing installation. The reaction time is approximately 10 secs.

Temperatures of Gases.—The temperature of the gases entering the precipitators is normally between 85° and 90° C. This corresponds to a fan temperature of 100° C. The gases leaving the precipitators are 10° to 15° C. below the entrance temperature. This agrees fairly closely with the figures given above for the dilution of the gases due to the entry of air up the insulator shafts.

Improvements in Efficiency.—The four factors upon which the efficiency of a treater depends appear to be—

(a) *The high-tension voltage.*—This determines the amount of onisation which takes place, and also the intensity of the electric field which secures the attraction of the particles of mist when they

have become charged. The maximum voltage, consistent with the dielectric distances, is desirable. This can be secured by—

(1) The even spacing of the electrodes, care being taken to adjust the spacing, whenever it is interfered with, *e.g.*, to permit of repairs being undertaken to the electrodes or any other part of the precipitator chambers.

(2) Care of insulators, these being kept well washed and clear from fume.

(3) Provision of adequate discharge distances throughout the chambers.

(b) *The velocity of the gases through the chamber.*—The greater this is the less satisfactory the ionisation and the greater chance there is of the intensity of the field proving insufficient to secure the deposition of the finer particles of mist, which will, therefore, be carried through the chamber unprecipitated. There is obviously a critical velocity, dependent to some extent on the density of mist to be precipitated. If the gases are forced through the chambers at higher speeds serious loss of efficiency must inevitably result.

(c) *The amount of mist present.*—This is, in all probability, the critical factor in determining the capacity of any treater. The greater the amount of mist present per unit volume of gases to be treated, the greater the work thrown upon the treaters, unless the total volume of gases to be treated is reduced proportionately. If the total volume of gases remains constant, and the percentage of mist is increased, there is considerable risk that the discharge from the discharge electrodes will prove unequal to the amount of ionisation required.

To secure the greatest efficiency from the precipitators, therefore, the mechanical scrubbing devices attached to the concentration plant should be made as efficient as possible. A decreased load on the precipitators, in the sense of a lower percentage of mist present in the gases to be treated, will certainly react on the overall efficiency of the plant. Reasons have already been assigned for the increased load which has recently been put on the electrical scrubber.

(d) *The rate of discharge from the discharge electrodes.*—This will be a function of the form of surface of the discharge electrodes, and the voltage of the H.T. current, but mainly of the former.

The rate of discharge is important in so far as it determines the total electric charge available for charging the mist particles. If it could be increased it would increase the efficiency, in that particles might be ionised which normally escape through the treater uncharged and, therefore, unprecipitated.

The experiment appears worthy of trial in a single chamber to instal three discharge electrodes between each pair of receiving electrodes instead of only two, as at present. This would conceivably increase the rate of discharge by 50 per cent. and the mist particles

G 2

would be required to pass through three streamr of charged air flowing from the discharge to the receiving electrodes, in place of two streams as at present.

Any benefit resulting could only be an increased chance of ionising the mist; the intensity of the electric field would remain almost unchanged. This point is important when a gas has to be treated containing a high percentage of mist.

The alternatives to this arrangement are either a lengthening of the treaters, with an increase in the number of receiving electrodes, as well as of the discharge electrodes, or else a considerable reduction in the velocity of the gases through the treater. Either alternative would increase the reaction time for each particle of mist passing through the treater.

ELECTRICAL DATA.

Treaters.—The current applied to the primary circuit of each electrical unit is 15 to 16 ampères at 440 volts.

Average power consumption per day for four units is 620 kw. hours.

Average voltage at the Cottrell treaters is 73,600 volts.

The voltage possible on the treaters is higher at present[*] than it has been at any previous time. During August 1917, the first month of working, the average voltage was 59,000 volts, and during November of the same year, 69,800 volts.

The fact that the present figure represents the maximum attained points to steady improvement in the efficiency of the electrical plant. This is due in the main to—

(a) The partial substitution of ohmic for inductive resistance, as already described.

(b) Adequate attention to insulators.

(c) Improvement in fan draught.

(d) Operation of bye-pass, whenever the pressure becomes too great.

(e) Care in spacing of electrodes.

Cottrell Fan.—Average power consumption per 24 hours is 1,930 kw. hours.

Average current supplied is 100 ampères at 440 volts.

The only estimate of the rate of discharge of the fan was made by using a vane anemometer at the apex of the ejector cone.

The velocity at the apex equals 150 feet per second, giving a volume discharge of 40,000 cubic feet per minute. This result was obtained with 635 r.p.m.

It was expected originally that the correct speed of the fan would be in the neighbourhood of 570 r.p.m., and that at this speed it would

* See footnote, page 72.

develop a pressure of $1\frac{1}{2}$ inches water, and be capable of dealing with approximately 50,000 cubic feet air per minute.

PRECIPITATED ACID AND NITRO-BODY.

Strength of Acid.—This has remained constant in the region of 51 per cent. H_2SO_4, the temperature of the gases entering the treater having been kept at a fairly constant figure.

This dependence of strength of deposited acid upon temperature is indicated by the following table which shows the variation in strength of the fan drip acid with the temperature of the gases passing through the fan.

Temperature of gases °C.							Strength of fan drip acid per cent. H_2SO_4.
110	-	-	-	-	-	-	59·6
102	-	-	-	-	-	-	59·0
98	-	-	-	-	-	-	56·9
90	-	-	-	-	-	-	55·0

Amount recovered.—The tonnage of acid recovered averages at present about 30 tons of 51 per cent. H_2SO_4 per day. In a recent test, 29·0 tons of 51·1 per cent. H_2SO_4 were deposited for an amount of 420 tons H_2SO_4 charged to the concentrating plant as 67·5 per cent. H_2SO_4. This represents about 3 to 3·5 per cent. of the total H_2SO_4 charged to the concentrators.

The loss of SO_3 up the stack is about 1·0 to 1·2 per cent. of the tonnage charged. This gives a Cottrell efficiency of about 70 to 75 per cent. As far as tests show, this efficiency has been fairly steady, although the amount of acid recovered in the plant and the SO_3 content of the gases escaping to the stack have both increased. This indicates an increased load on the Cottrell, which is probably due to the following :—

(a) On account of changes in the working of the TNT acids cycle, it has been necessary to raise the concentration figure from 90·5 per cent. to 93 per cent. The higher furnace and tower temperatures necessary to secure this may have increased the amount of dissociation which has taken place.

(b) Fuming from the tower domes has been largely stopped by improvement in the offtakes and general reduction of resistance in the gas circuit.

The loss of fume in this way was, at one time, very considerable. All this fume now passes through the Cottrell chambers.

(c) The increase in the capacity of towers 3 and 12 has thrown extra work on the coke scrubbing system of these towers.

This scrubbing capacity is probably fairly constant, so that an increased load has been thrown on the Cottrell chambers on this account.

Treatment of Cottrell Acid.—The handling of the Cottrell acid up to date has been complicated by the presence of the contained nitro-body. The acid runs off at a temperature of about 70° C., and displays a thin black scum of oil, dinitrotoluene, and carbon, the latter representing mainly coke carried over from the scrubbers. Upon cooling or diluting the acid, a well-defined crystalline body separates out, which is very soluble in ether or alcohol. This is pratically pure 2 : 4 dinitrotoluene. In addition, there is a little oily matter which is probably mononitrotoluene. Upon concentrating the dilute acid to 92 per cent. all the dinitrotoluene volatilises with the vapour and is lost. The concentrated acid contains only a trace of oily matter soluble in ether.

Numerous schemes have been suggested for dealing with the Cottrell acid. The present practice is to pump the hot acid by means of a silicon-iron centrifugal pump to the scrubber storage tanks, and to charge the acid to the Gaillards along with the recuperator acid. No undue blocking of sprays has resulted, although, if the recuperator acid were cooled, as is ultimately to be the practice, trouble of this kind is to be anticipated.

At present only 70 to 100 lb. nitro-body per day are recovered. The super-detofuation scheme at the TNT nitrating houses should remove the difficulty almost entirely.

Nitro-body in Cottrell Acid.[*]—The acid concentrated at the Gaillard towers is the acid resulting from the denitration of spent acids produced in the manufacture of mononitrotoluene and TNT. The mixed acids provided for both stages of the nitration are mixed from fresh acids, the revivification scheme for mononitrotoluene mixed acid having been abandoned for various reasons.

TNT spent acid as received at the denitrating plant contains about 0·80 per cent. of nitro-body, of which about 0·15 per cent. to 0·20 per cent. is mononitrotoluene and 0·60 per cent. to 0·65 per cent. dinitrotoluene. The spent acid from the manufacture of mononitrotoleune contains up to 0·4 per cent. to 0·5 per cent. of mononitrotoluene.

There is little trouble in dealing with dissolved mononitrotoluene as the mononitrotoluene steam-distils in the denitration process, and is condensed in the Hart condensers attached to that plant, being recovered from the Hart condensate by a simple separation scheme, involving the dilution of the nitric acid recovered, in order to reduce its gravity substantially below that of the mononitrotoluene. The latter js then separated off and pumped back to the TNT nitration plant. The chief trouble arises with the dinitrotoluene, which does not distil off at the denitrators, but proceeds in solution in the denitrated acid to the concentrating plant. Here it is volatilised at the high temperatures

obtaining in the towers, and is conveyed to the precipitating plant. Analysis of the gases in the flues leading to the Cottrell precipitator show an average of 3·5 to 4·0 gm. of nitro-body (mainly dinitrotoluene) per 100 cubic feet. This is equivalent to about 2 tons of dinitrotoluene per day, which is at present almost entirely lost. The wet setting point of this dinitrotoluene may be taken as about 55° C.; and whenever the temperature within the flues or treaters reaches this figure, deposit of nitro-body will take place. Experience has shown that this happens in the treaters whenever the temperature of the gases entering is below 70° to 72° C. This will be reduced, inside the treaters, to a temperature below 55° C. by the cold air passing up the insulator shafts, especially in the neighbourhood of the port-holes.

The question of possible danger arising by reason of the deposit of nitro-body in the chambers having been raised, some dinitrotoluene crystals were subjected to a sustained arc of 30,000 volts, but showed no tendency to fire. The ignition temperature was well over 300° C.

Effect of super-detoluation of TNT spent Acid.—As has been shown, there is little difficulty in dealing with mononitrotoluene in the spent acid, so that mononitrotoluene spent acid obtained from nitrating with fresh mixed acid presents no problem. The superdetoluation process at present in operation at one TNT nitrating house, and ultimately to be introduced throughout, aims at :—

(1) Reducing the nitro-body in TNT spent acid; and

(2) Eliminating, as far as possible, the present dinitrotoluene content.

The spent acid separated from the detoluators is mixed with a charge of mononitrotoluene which largely dissolves the dinitrotoluene in the spent acid, leaving in solution only about 0·3 per cent. of mononitrotoluene, which will be mostly recovered at the denitrators by means of the existing arrangement. Super-detoluation should, therefore, result in the recovery and utilisation in subsequent nitrations of the bulk of the 2 tons of dinitrotoluene at present passing to waste up the Cottrell stack.

Effects of cooling the Lead Flues.—The suggestion has been made, as a means of increasing the efficiency of the precipitation plant, to lower the temperature of the gases entering the Cottrell chambers by cooling the lead flues leading from the fans to the precipitator. The effects of this are seen to be :—

(a) An increase in the amount of acid deposited in the flues themselves.

(b) A consequent decrease in the mist-content of the gases passing to the Cottrell plant. This would certainly contribute to an increase of efficiency.

(c) A diminution in the strength of the acid recovered from the Cottrell plant. Inasmuch as this acid, together with the acid deposited in the lead flues, has to be reconcentrated, an

increased tonnage of water would need tó be driven off at the concentrators, so that the load on this plant would be increased.

(d) Under present working conditions, trouble would certainly arise, on account of serious depositing of nitro-body in the flues, as well as in the treaters. This objection, however, will not obtain when the super-detoluation scheme is in full operation. For this reason, no cooling should take place at present.

Should cooling ever be thought desirable and feasible, the soundest and most economical scheme would probably be to bring about the reduction in gas temperatures by the admittance of air in the main tower offtake. This would obviate the difficulty of installing special cooling devices in connection with the lead flues, and, provided the fans could cope with the increased volume of air, the decreased fan temperatures would contribute substantially towards the reduction in the cost of fan maintenance, which is largely a problem of temperature.

CLEANING AND MAINTENANCE OF PRECIPITATORS.

The Gaillard towers are usually closed down for 8 to 10 hours once every week or ten days to enable the burning out of the flues to take place. This is made the occasion for the cleaning down of the units. The necessary repairs to the leadwork and brickwork are made at the same time.

Cleaning.—Upon opening up the precipitators, the first row of discharge electrodes and the faces of the first row of receiving electrodes upon either side of the precipitating chambers are invariably found to be coated, to a depth of $\frac{1}{2}$ inch to 1 inch, with closely packed fine crystals of 2 : 4 dinitrotoluene. This deposit is due to the cooling occasioned by the entrance of cold air from the insulating shafts, and the deposit grows thicker as the outlet end of the chamber is approached. The crystals are readily washed off by means of a hose-pipe.

The insulating chambers are usually fairly clean and dry. If, however, one or another of them has been opened up when the shaft is full of fume, the cold draught has caused a similar deposit of nitro-body crystals, which is discovered when the cleaning down takes place.

Maintenance.—Certain routine repairs to the lead-work are necessary whenever the plant is closed down. It is significant that these repairs are only necessary to lead-work which has been in contact with iron.

Certain of the supports to the receiving electrodes invariably require replacement. The temperature in the precipitator causes the lead-work to creep and crack, so that the acid deposited is able to obtain admittance to the space between the lead and steel, where it causes a rapid swelling and bursting of the lead covering, due doubtless

FIG. 26.

SHEWING THE EFFECT OF THE ACTION OF ACID ON THE LEAD COVERED M.S. PIPE

USED AS SUPPORTS FOR RECEIVING ELECTRODES.
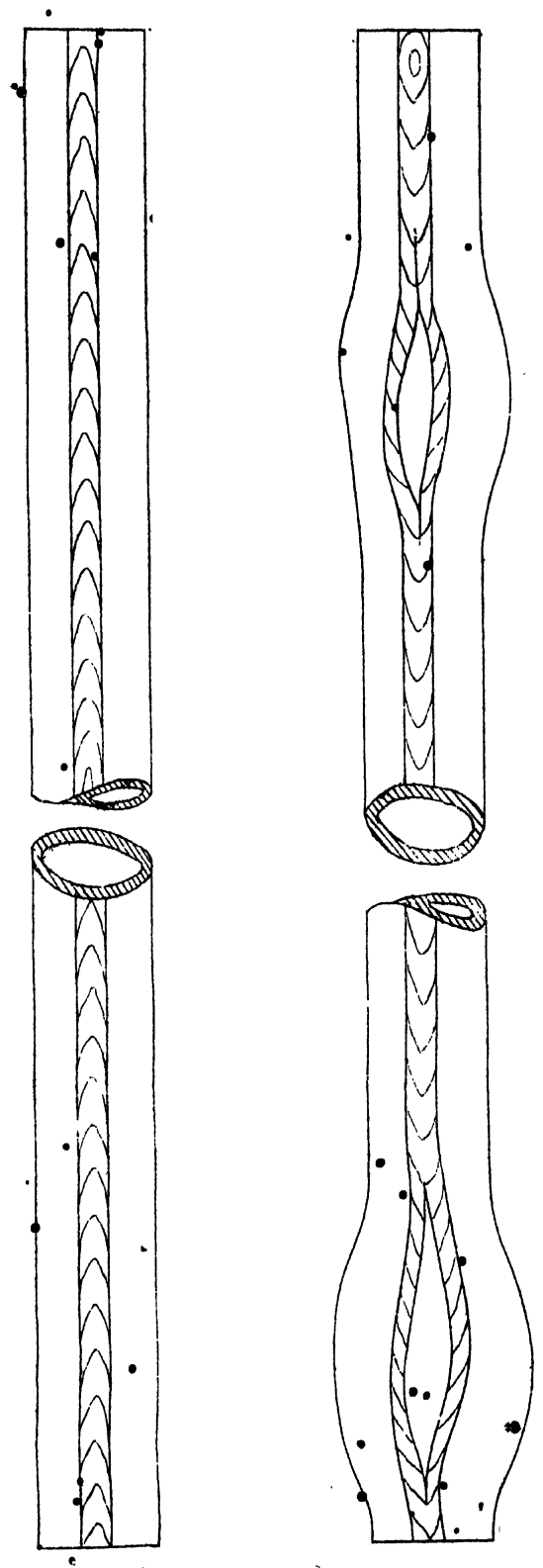
to the formation of gas between the two metals. Fig. 26 shows the appearance of a receiving electrode support which has been attacked in this way. Similar action occurs wherever lead is used as a covering for iron. Up to the present, all covering has been in 6-lb. lead. The trouble would probably be lessened by the utilisation of heavier lead.

Up to the present no lead coverings to the woodwork have suffered corrosion in this way.

Certain troubles have also arisen in connection with the covers to the chambers. These are of wood to' which a lead covering is nailed on below, the nails being ordinary steel wire nails, which are afterwards covered over with a lead patch. The acid, however, gets behind' the lead and corrodes the nails, causing sagging of the lead-work. The remedy is probably the substitution of regulus nails or rivets for the present steel nails.

The tops of the covers are covered with a coating of rubberoid. The heat of the chambers tends to soften this, however, causing exposure of the woodwork, which soon becomes saturated with acid, and then rots. The covers should not be flat, therefore, but slightly arched, so that any rain or moisture falling on them will drain off automatically.

The chief maintenance required in addition to the above is frequent pointing of the brickwork.

The stack, however, shows little signs of wear. In the first days of working the plant, nitro-body settled in the throat of the stack and had to be scraped down periodically. This accumulation has been overcome by bye-passing all the gases every week or two for a period of four or five hours. This dissolves and loosens the nitro-body which falls to the base and is carried away in the acid which drains from the stack.

The stack has recently been as long as 10 weeks without being opened up. At the end of that period, examination showed only a small accumulation of nitro-body in the throat. This was not sufficient in amount to cause any serious resistance to the fan draught or to the escape of the waste gases.

In addition to the weekly shut-down of the plant, the current is occasionally switched off each unit for five minutes or so, for the insulators to be washed and cleaned.

APPENDIX.

THE FREE CROSS-SECTION THROUGH COKE FILTERS OF ANY SIZE OR GRADE OF PACKING.

Assuming each particle of coke to be perfectly spherical in form and packed in the filter so that each of the spheres are touching one another, then, from Fig. 28, the space occupied by 1,000 spheres will be $10 \cdot 5\,d$ in length by $8 \cdot 66\,d$, in height and width, which gives a cubical space of :—

$$787 \cdot 45\,d^3, \text{ where } d = \text{diameter of spheres.}$$
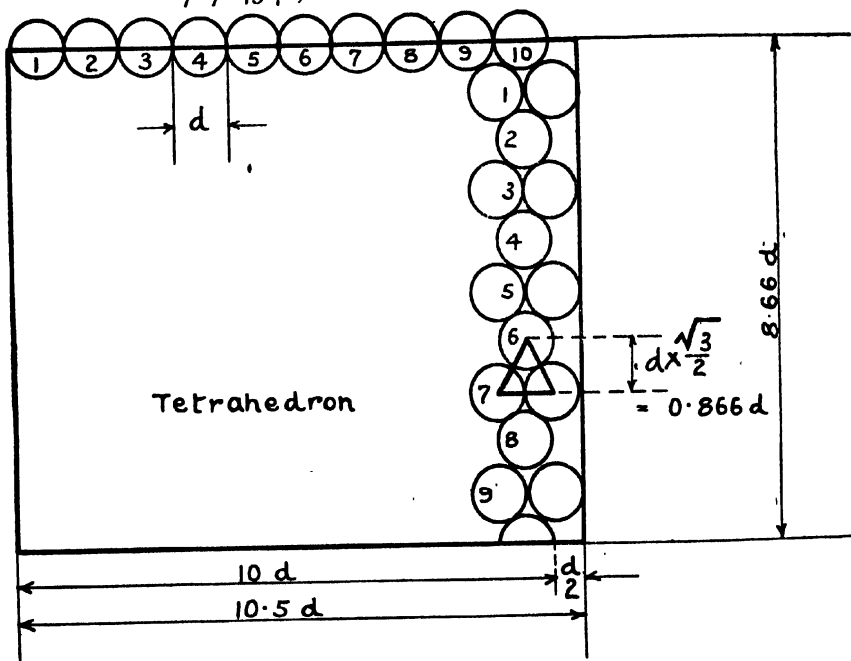

FIG. 28.

The box containing 1,000 spheres all touching (Fig. 28) is, however, not truly cubical, but since the space occupied by 1,000 spheres is found to be $787 \cdot 45\,d^3$, then the side of a cube of equal content will be.

$$\sqrt[3]{787 \cdot 45\,d^3} = 9 \cdot 2344\,d.$$

Now the volume of a sphere $= \quad \dfrac{\pi}{6}\,d^3 = 0 \cdot 52359\,d^3,$

and the volume occupied by 1,000 spheres $= 787 \cdot 45\,d^3,$
but the actual volume of 1,000 spheres $= 1,000 \times 0 \cdot 52359\,d^3$
$= 523 \cdot 59\,d^3.$

volume of space (free space) between 1,000 closely packed spheres

$$= (787 \cdot 45\,d^3 - 523 \cdot 59\,d^3) = 263 \cdot 86\,d^3,$$

and percentage of free space

$$= \frac{263 \cdot 86 \; d^3}{787 \cdot 45 \; d^3} \times 100 = 33 \cdot 5 \text{ per cent.}$$

Free Cross-Section for Flow of Gas.

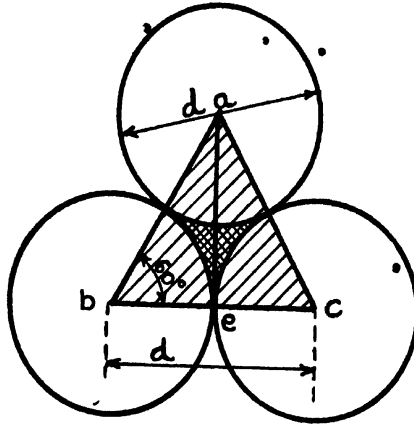The minimum free cross-section will occur between any three spheres touching one another as shown in Fig. 29.

FIG. 29.

Then
$$a e = d \times \frac{\sqrt{3}}{2} = 0 \cdot 866 \; d,$$

and area of triangle

$$a \, b \, c = \frac{d \times 0 \cdot 866 \; d}{2} = 0 \cdot 433 \; d^2.$$

Area of three segments of circle each containing an angle of 60° = area of segment of circle containing 180°

$$= \frac{d^2 \times 0 \cdot 7854}{2} = 0 \cdot 3927 \; d^2.$$

∴ free cross-section

$$= (0 \cdot 433 \; d^2 - 0 \cdot 3927 \; d^2) = 0 \cdot 0403 \; d^2,$$

and percentage of free cross-section

$$= \frac{0 \cdot 0403 \; d^2}{0 \cdot 433 \; d^2} \times 100 = 9 \cdot 55 \text{ per cent.}$$

Wetted Surface of Packing.

Area of sphere $= \pi \, d^2$.

∴ area of 1,000 spheres $= 3,141 \cdot 6 \; d^2$.

From the previous calculations the following table (No. 1) has been computed showing the free space, cross-section, &c., for spheres of $\frac{1}{16}$-inch diameter to 6-inch diameter.

Table 1.

Diameter of sphere.	Side of cube to contain 1,000 spheres.	Number of spheres per cubic foot	Free space.	Free cross-section.	Wetted surface per cubic foot of packing.
Inches.	Inches.		Per cent.	Per cent.	Square feet.
$\frac{1}{16}$	0·577	9,000,000	33·5	9·55	765·0
$\frac{1}{8}$	1·154	1,122,000	,,	,,	382·0
$\frac{3}{16}$	1·731	332,000	,,	,,	251·0
$\frac{1}{4}$	2·308	140,000	,,	,,	191·0
$\frac{5}{16}$	2·885	71,800	,,	,,	153·0
$\frac{3}{8}$	3·462	41,400	,,	,,	127·0
$\frac{1}{2}$	4·616	17,500	,,	,,	95·5
$\frac{3}{4}$	6·924	5,200	,,	,,	63·7
1	9·232	2,170	,,	,,	47·3
$1\frac{1}{2}$	13·848	648	,,	,,	31·8
2	18·464	274	,,	,,	23·8
3	27·696	81	,,	,,	15·9
4	36·928	34·4	,,	,,	12·0
6	55·392	10·15	,,	,,	7·9

From the above table it is seen that the percentage of free space and of free cross-section is quite independent of the size of the particles of the packing, but the wetted surface varies greatly.

This is only true, however, of a non-elastic or non-compressible substance, whereas in practice it is known that coke when crushed is easily compressed within certain limits.

The amount of compressibility of crushed coke may be illustrated by the following table, which gives the weight of coke of various sizes per cubic foot.

Table 2.

| Gauge.	Weight per Cubic Foot.
2-inch - - - - - - -	28 lb.
1½-inch - - - - - -	30 lb.
1-inch - - - - - - -	32·5 lb.
½-inch - - - - - - -	33·0 lb.
¼-inch - - - - - - -	34·0 lb.
⅛-inch - - - - - - -	34·25 lb.

The greater density of crushed coke of the smaller sizes will have the effect of reducing the free cross-section and also the wetted surface per cubic foot of packing.

Table 3.

Probable actual Free Space, Free Cross-section and Wetted Surface of Coke Packing of various Sizes.

Size of coke.	Free space.	Free cross-section.	Wetted surface per cubic foot of packing.
Inches mesh.	Per cent. volume.	Per cent. of area.	Square feet.
$\frac{1}{16}$	27·25	7·67	540·0
$\frac{1}{8}$	27·35	7·70	271·0
$\frac{3}{16}$	27·50	7·73	190·0
$\frac{1}{4}$	27·60	7·77	142·0
$\frac{5}{16}$	27·75	7·80	112·0
$\frac{3}{8}$	27·90	7·84	95·0
$\frac{1}{2}$	28·25	7·90	72·0
$\frac{3}{4}$	28·60	8·06	45·0
1	29·10	8·20	35·0
1½	29·80	8·50	25·0
2	30·50	8·80	21·0
3	31·60	9·30	15·7
4	33·00	9·50	12·0
6	33·50	9·55	7·9

The reduction in wetted surface was calculated as follows:—
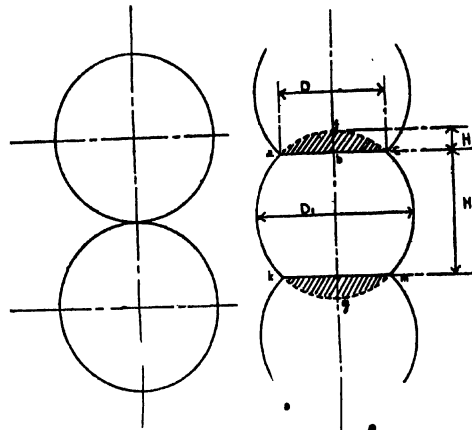
PARTICLES OF COKE BEFORE COMPRESSION.   PARTICLES OF COKE AFTER COMPRESSION

FIG 30.

Assume original weight of sphere to be 28 lb., then, when com-pressed to its maximum density of 34 lb., its volume will be reduced in the ratio of $1 : \frac{28}{34}$ or 100 : 82, i.e., each of the shaded volumes a, f, c, b, must represent 9 per cent. of the original volume of the spheres.

Let diameter of sphere $D = 10$ inches.

Then volume of sphere—

$$= \frac{\pi d^3}{6} = \frac{3 \cdot 1416 \times 1,000}{6}$$

$$= 524 \text{ cubic inches.}$$

And 9 per cent. of 524 = 47·1 cubic inches = volume of segment above line $a, c.$

Volume of segment of sphere

$$= \frac{\pi H^2}{6} (3 D - 2 H).$$

Then

$$47 \cdot 1 = \frac{3 \cdot 1416 \, H^2}{6} (30 - 2 H)$$

$$\frac{47 \cdot 1 \times 6}{3 \cdot 1416} = 30 \, H^2 - 2 \, H^3$$

Whence, by graphical solution H = 1·85 inches.

Area surface of sphere before compression

$$= \pi d^2 = 3 \cdot 1416 \times 100 = 314 \text{ square inches.}$$

Area of segment of sphere (curved surface only)

$$= \pi D_1 H.$$

Now

$$H \times H_1 = (b, c)^2, \text{ or } b, c = \sqrt{H \times H_1}, \text{ and } D_1 = 2\sqrt{H \times H_1}$$

$$\therefore \text{ area of each segment} = 6 \cdot 28 \times H\sqrt{H \times H_1}$$

And area of top and bottom segment will be twice the above, or—

$$12 \cdot 56 \, H\sqrt{H \times H_1}$$

$$= 12 \cdot 56 \times 1 \cdot 85 \sqrt{1 \cdot 85 \times 8 \cdot 15}$$

$$= 90 \cdot 4 \text{ square inches.}$$

Area of sphere before compression = 314·16 square inches.

Area of sphere after compression = (314·16 − 90·4) = 223·76 square inches.

$\therefore$ Final area is $\dfrac{223 \cdot 76}{314 \cdot 16} = 71$ per cent. of the original.

By similar calculations, values for other compression can be made.

Pressure required to Force Gases through the Coke.

The pressure required to force the gases through the filter bed will vary with the size of the coke particles, and with the velocity.

By examination of several known cases, the following empirical formula seems to agree fairly closely with practice:—

$$p = C \times 0.6\,K \times V^2 \times d.$$

Where p = drop in pressure in thousandths of an inch.

    $C = 0.1$ (a constant).

    K = wetted surface of packing per cubic foot.

    V = velocity of flow through packing.

    d = depth of bed in feet.

Table 4.

Table of Co-efficients K.

Size of coke.	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	3	4	6
K	540	271	190	142	112	95	72	45	35	25	21	15·7	12	7·9

Table 5.

Table showing Results of Formula against Actual Practice.

Filter or other similar apparatus.	Size of packing. Inches.	Depth of bed. Feet.	Gas velocity. Ft. per sec.	Loss of pressure. Inches of water. Observed.	Loss of pressure. Inches of water. Calculated.
Grillo plant scrubbing towers (3)	About 5	58·5	5·22	0·8	0·950
Grillo plant filters, Queen's Ferry Units A, B, and C.	$\frac{1}{8}$ to $\frac{3}{16}$	4·0	1·98	0·2	0·215
Grillo plant converter - -	$\frac{3}{8}$	6·18	11·30	4·5	4·460